THE ADVANCED ENERGY® PE 2500 GENERATOR

User Manual

Option: 100 kHz, load matching

PN: 5700248-B
October 1992

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Option: 100 kHz, load matching

ADVANCED ENERGY INDUSTRIES, INC

1600 Prospect Parkway
Fort Collins, Colorado 80525
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Telex #45-0938

PN: 5700248-B
October 1992

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SAFE OPERATING PROCEDURES AND PROPER USE OF THE EQUIPMENT ARE THE RESPONSIBILITY OF THE USER OF THIS SYSTEM.

Advanced Energy Industries, Inc., provides information on its products and associated hazards, but it assumes no responsibility for the after-sale operation of the equipment or the safety practices of the owner or user.

This equipment produces potentially lethal high-voltage, high-current, radio frequency (RF) energy. You should read this manual and understand its contents before you attempt to hook up or operate the equipment it describes. Follow all safety precautions. **Never defeat interlocks or grounds**.

DANGER! All personnel who work with or who are exposed to this equipment must take precautions to protect themselves against serious or possibly fatal bodily injury.

DO NOT BE CARELESS AROUND THIS EQUIPMENT.

CONGRATULATIONS ...

On your purchase of AE's PE generator, designed for hard use in a vacuum environment. Advanced circuit design and calibrated instrumentation make these units the most accurate, most efficient, and most versatile in the world today.

Since 1981, AE's power supplies and controllers have been contributing to a broad range of advanced technological processes such as semiconductor fabrication, optical coating, printed circuit manufacturing, glass coating, and data storage media plating. In the United States, Europe, and Asia, Advanced Energy Industries, Inc., is known for its quality products and strong customer support.

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INTRODUCTION

OVERVIEW OF THE MANUAL

The main table of contents is an outline of the major topics covered in the manual. It shows each chapter and the major sections of each chapter. It contains only the major sections so that you can skim it and get a general idea of what is contained here, without having to look at a lot of headings. In the manual, the chapter titles and the major sections are printed at the top right-hand corner of each odd-numbered page.

When you turn to a chapter, you will find a detailed table of contents that lists each subheading in the chapter. This will show you which page contains the information you are looking for.

Part 1, Getting to Know Your PE Series Generator, contains two chapters: What It Is and How It Works. What It Is gives an overview of the PE and a description of the functional and physical specifications.

How It Works contains a functional block diagram, a description of the front panel controls and status indicators, and important information on connectors and signal descriptions.

Part II, Operating Your PE Series Generator, also contains two chapters: Preparing for Use and Choosing Modes. Preparing for Use provides information on unpacking, connecting, and starting up your PE. Choosing Modes tells you how to select remote control.

Part III, Servicing Your PE Series Generator, contains one chapter, Calibration and Troubleshooting. This chapter tells you how to adjust the PE and service minor problems.

Part IV, Learning More About Your PE Generator, contains a detailed description of grounding techniques.

INTERPRETING THE MANUAL

Type Conventions

To help you quickly pick out what is being discussed, the manual presents certain words and phrases in type that is different from the rest of the text. Pin and line names appear in capitalized italics (*POWCOM*). Labels that are on the PE (switches, indicators, etc.) generally appear in boldface capital letters (**PLASMA**). Functions are printed in boldface lowercase letters (**on/off**).

PART I

GETTING TO KNOW YOUR PE SERIES GENERATOR

PART I

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GENERAL DESCRIPTION

The PE series power supply is designed as a power source for plasma processes. The unit delivers power and holds power at the specified level during plasma variations.

You can control the output and monitor the unit either from the front panel or through an I/O connector provided on the rear panel. PE series units easily interface with most logic types and both relay and switch contact closures.

The PE 2500's load-matching network is needed for a wide range of loads. At a given power level and pressure, plasma operates at a fixed voltage level much like back-to-back zener diodes. Load matching is required when this voltage is not in the operating range of the power supply.

The PE series uses a resonant power conversion technique coordinated with a highly effective line filter. This produces extremely efficient operation typical of switching power supplies while maintaining the low electromagnetic interference (EMI) of linear power supplies.

Understanding Switch-mode Operation

There are two basic approaches to ac power generation. The first, most common, is linear operation. The second, more recent development, is switch-mode operation. The following discussion explains the significant differences between the two types of operation.

Both linear and switch-mode supplies use an input rectifier/filter; however, linear supplies require a large 60-Hz step up/step down transformer. This transformer means that linear supplies are larger and heavier than switching supplies of the same power rating.

Another significant difference between linear and switching power supplies of a given frequency is the control element. Linear supplies use transistors or tubes as variable resistors that gradually change their value in response to a control signal. This gradual change causes the supply to dissipate nearly as much (possibly more) heat as the load. If transistors are used, an additional problem called "secondary breakdown" is common. Secondary breakdown

prevents full device use, so large numbers of devices must be combined to produce the required power.

In contrast, switch-mode supplies use transistors optimized for rapid "turn on" and "turn off" in series with the load. Because each switch is always either fully on or off, switch-mode supplies dissipate significantly less power than do linear supplies.

One drawback of using switching supplies with plasma processes is that a plasma requires a current or "energy" source for proper stabilization. Most switching supplies are voltage sources.
The PE series deals with this problem in a unique fashion. First, a reactive power filter with a pass characteristic at the fundamental frequency acts as an energy source. The filter supplies both the voltage and current that the plasma requires for stability, and in addition, isolates transients (arcs, for example) from the generator. Because of the smoothing effect of the filter, the switches can be pulse-width modulated, and power control is attained with the same devices used for power generation. Hence the description, pulse-width modulated resonant inverter.

SPECIFICATIONS

Functional Specifications

Controlling Modes	Local (through the front panel), remote (through the User I/O port).
Control Signal Sources	Power output can be controlled by internal analog signals entered from the front panel, or by external analog signals provided from the user I/O port.
Power Output	Low frequency output controlled in the constant power mode.
Interlock Supervision	When connected to a safety switch, the interlock string disables the unit if a problem occurs.
Status Indicators	LED's on front panel show status of interlocks, output enable, plasma ignition, and setpoint level. Remote or local control is also shown.
Fault Conditions	Overtemperature and arc are the conditions that shut off the output power.
Internal Load-matching	The load-matching network's voltage transformer correctly matches the voltage of the power supply to the voltage of the load.

Physical Specifications

Input Voltage	208 V ac ± 10% 50/60 Hz single phase
Input Current	20 A nominal (full power) 0.72 power factor 25 A circuit breaker
Output Power	1700 W at 550 V nominal output
Output Frequency	100 kHz ± 100 Hz
Ambient Temperature:	
Operating	Minimum 0°C, maximum 40°C (maximum value of average over 24 hr.: 35°C). If the units are enclosed in cabinets, the operator will ascertain the temperature at the place of installation and ensure that the maximum ambient temperature is not exceeded.
Storage	Minimum -25°C, maximum 55°C.
Transportation	Minimum -25°C, maximum 55°C (for short periods of up to 24 hrs., the maximum is 70°C).
Coolant Temperature	Air (gas) minimum 0°C, maximum 35°C.
Coolant Flow Parameters:	
Contamination	Cooling air should be free of corrosive vapors and particles, conductive particles, and particles that could become conductive after exposure to moisture.
Humidity	15-85% relative humidity; no condensation or icing.
Atmospheric Pressure:	
Operating	800 mbar minimum (approx. 2000 m above sea level).

Storage	800 mbar minimum (approx. 2000 m above sea level).
Transportation	660 mbar minimum (approx. 3265 m above sea level).

PART I

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THEORY OF OPERATION

The PE converts ac line power into rectified dc voltage. The dc voltage provides an unregulated source for high-frequency inverters. The inverters convert the unregulated dc voltage to high-frequency ac voltage.
The following sections describe the functional units of the PE power supply. Figure 2-1 on page 2-4 shows the PE block diagram.

Circuit Breaker/EMC Filter

The circuit breaker located on the rear panel automatically protects the system wiring in the event of a failure. In some units a fuse is used instead of a circuit breaker. The internal EMC filter reduces the amount of high-frequency noise conducted to the power lines.

Main Contactor/Rectifier

The main contactor applies incoming ac voltage to the rectifier. The rectifier converts the ac input to unregulated dc voltage.

Filter/Soft Start

The input filter reduces EMI conducted at low frequencies. It also reduces the peak current through the rectifier and the dc filter capacitor, and provides a stable input impedance for the dc-to-ac regulator.

The soft start circuit prevents large surge currents when the input power is turned on. The circuit uses a 50 Ω resistor to charge the dc filter capacitor and then shorts this resistor when the dc filter cap is charged to the normal operating level.

Auxiliary Power Supply

The auxiliary power supply is a 50/60 Hz transformer with an isolated 40 V ac center-tapped winding. The secondary winding generates ±24 V dc to power the control electronics.

Drive Board

The drive board provides isolation between the control logic and the inverter.

Inverter/Frequency Module/Output Transformer

The inverter chops the dc voltage into a square wave ac voltage that passes through a series resonant circuit to produce a sine wave. This sine wave passes through an isolation (output) transformer.

Internal Load Matching Transformer

The transformer's taps allow the PE to efficiently transfer power to a wide range of loads.

Output Sense

The output sense converts and isolates output voltage and current to logic levels.

Display/User I/O

The display provides status information and control from the front panel. The user I/O port interface provides status and control for the remote interface.

Logic

The logic provides fault protection, on/off control, and power regulation for the power supply. Additional fault protection is provided by the fold-back current board which plugs into the logic board. The fold-back current feature monitors output, voltage and current phase and limits output power if they become excessive, thereby prolonging the life of the inverters.

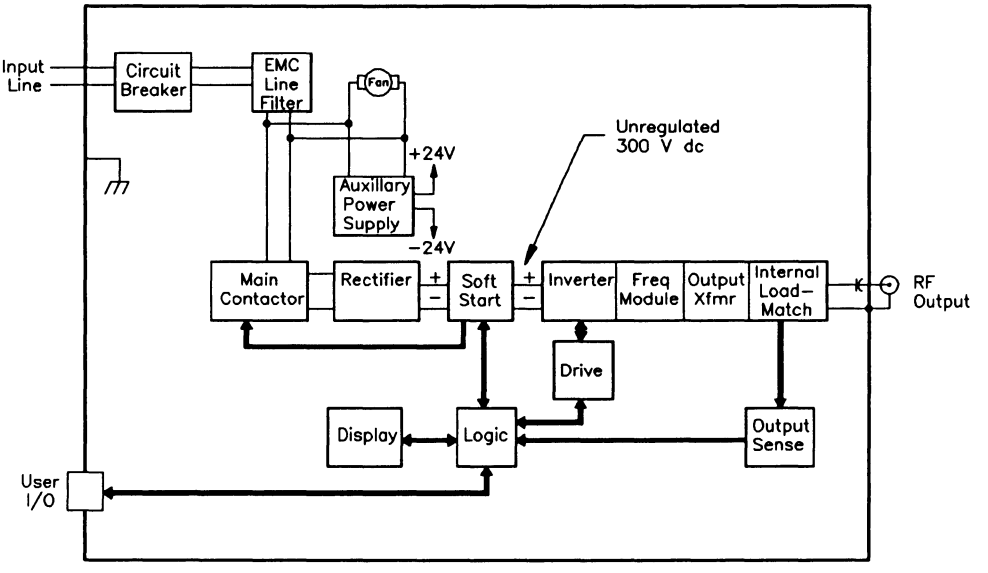


Figure 2-1. PE block diagram.

FRONT PANEL CONTROLS

The switches described below provide complete control of the PE power supply from the front panel. Figure 2-2 on page 2-6 shows the front panel.

POWER ON/OFF — Applies line power to internal circuitry.

OUTPUT ON/OFF — **OFF** resets the interlocks and overtemperature fault and removes the output power. **OFF** resets in both local and remote modes. However, in remote mode, power remains off only as long as the switch is held off. **ON** enables power to be transferred to the output connector. **ON** works only in local mode.

LEVEL — Controls output power in local mode. Rotating the locking skirt clockwise locks the knob in position without changing the setpoint value. The control has 10 turns and 0.1% resolution.

REMOTE/LOCAL — The two-position switch under the **LEVEL** knob selects remote or local control for the signal that programs power level. The two-position switch located under **OUTPUT ON/OFF** switch selects remote or local control for enabling the output.

DISPLAY — A momentary toggle switch that selects values to read on the **MONITOR** display. The middle or neutral position displays power in kilowatts. The upper and lower positions display voltage and current, respectively. Analog values of these signals are continuously available at the rear I/O connector.

TAP NUMBER Selects transformer taps 1-10. Tap number 10 has the highest voltage out, and tap number 1 has the lowest votlage out.

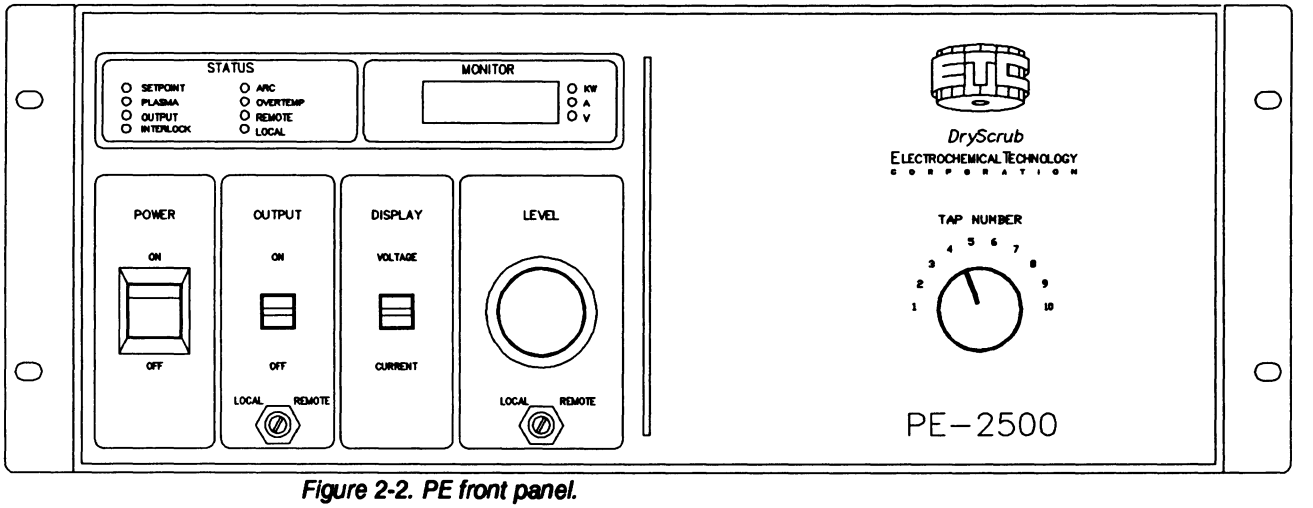


Figure 2-2. PE front panel.

STATUS INDICATORS

The PE power supply can be monitored by checking the following **STATUS** indicators on the front panel.

INTERLOCK	Lights when all interlocks are satisfied. Flashes when the interlock chain is broken. Unlit when the remote I/O connector is not in, the **OUTPUT OFF** momentary rocker position is actuated, or the remote *XOFF.D* command is active (high).
OUTPUT	Lights when the main contactor is closed, and the output is enabled and ready to deliver power.
PLASMA	Lights when over 1% of the full-scale output current has been reached (indicates plasma ignition).
SETPOINT	Lights when output power is within 0.2% of setpoint level. Flashes when there is a plasma indicated, but output power is further than 0.2% from setpoint level. Unlit when no plasma is present.
LOCAL	Lights to indicate unit is controlled through front panel.
REMOTE	Lights to indicate unit is being controlled through user I/O port.

OVERTEMP	Flashes when the temperature of the unit exceeds the factory-set limit. This turns off the unit until the temperature sensor cools and the supply is reset by setting the **OUTPUT ON/OFF** switch momentarily to **OFF**. Unlit when the operating temperature is normal.
ARC	Lights when an arc or an abnormally low process impedance occurs. The supply turns off within 1 ms after sensing this condition, withdraws the energy from the output power components, and in 3 ms reapplies power. The **ARC** indicator lights for 1 sec. after this event is sensed.

CONNECTORS

Analog/Digital I/O Connections

The user I/O interface uses the 15-pin, D subminiature, insulated connector shown on page 2-11. The Pin-description Table gives a brief description of each pin, for amore detailed discusion, see the page number referenced with each pin. Note: An ".A" appended to a pin name indicates an analog signal; a ".D" indicates a digital signal.

Pin-description Table

Pin	Name	Description	Refer to
1	*POWCOM*	digital and control common	Page 2-11
2	*24V*	can be either digital or analog, unregulated 24-V supply	Page 2-11
3	unassigned		
4	*XV.A*	output, 0-5 V	Page 2-11
5	*XSIG.A-*	input, 0-5 V, used with *pin 13*	Page 2-11
6	$\overline{XSPT.D}$	output, 0-15 V	Page 2-12
7	$\overline{INTLK.D}$	input, low -15 V dc to 3 V dc (a contact closure to *POWCOM* is sufficient low-logic level), high 11-30 V dc	Page 2-12
8	unassigned		
9	*SIGCOM*	analog common	Page 2-12

Pin	Name	Description	Refer to
10	unassigned		
11	XI.A	output, 0-5 V	Page 2-12
12	*XP.A*	output, 0-5 V	Page 2-13
13	*XSIG.A+*	input, 0-5 V, used with *pin 5*	Page 2-13
14	*XOFF.D*	input, low -15 V dc to 3 V dc (a contact closure to *POWCOM* is sufficient low-logic level), high 11-30 V dc, used with *pin 15*	Page 2-13
15	$\overline{\textit{XSON.D}}$	input, low -15 V dc to 3 V dc (a contact closure to *POWCOM* is sufficient low-logic level), high 11-30 V dc, used with *pin 14*	Page 2-13

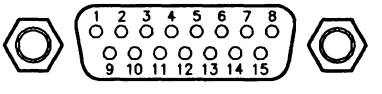
Signal Descriptions: User I/O Pins

The user I/O interface connector is shown below. An analog output is a 0-5 V dc signal referenced to *SIGCOM*. An analog input is a 0-5 V dc signal referenced to *XSIG.A-*. Both *XSIG.A-* and *XSIG.A+* must operate between 0 V and 10 V in reference to *SIGCOM*.

All input digital logic levels are as follows:

Low —
-15 V dc to 3 V dc
Note: A contact closure to *POWCOM* is a sufficient low-logic level.

High—
11 V dc to 30 V dc
Note: An open to the inputs is a sufficient high-logic level.



pin 1. POWCOM. This signal is a dedicated ground that returns to the internal system ground, then the chassis ground, and finally to the safety ground. All digital and control connections are referenced to *POWCOM*.

pin 2. 24V. This signal is a source of unregulated voltage between 22 V and 35 V with a 1/4 W, 100 Ω resistor in series. This may be used as a low current (maximum 50 mA) auxiliary power source (see the discussion of *pin 6, $\overline{XSPT.D}$)*.

pin 3. unassigned

pin 4. XV.A This output signal provides a fully buffered 0-5 V dc signal representing full-scale output voltage at 1200 V rms. The impedance of the *XV.A* output is 100 Ω.

pin 5. XSIG.A- This input signal and *XSIG.A+* (*pin 13*) provide a differential pair that can be used to linearly control the output power of the supply. This control point is active when the **REMOTE/LOCAL** switch on the front panel

(units built after Feb. 1989) OR the DIP switch on the logic board (units built prior to Feb. 1989) is in the **REMOTE** position. See page 4-3 for more information on selecting remote control. A 0-5 V dc input provides linear control from 0 W to full power. The impedance of these inputs is 1 MΩ. The common mode range is 0-10 V.

pin 6. $\overline{XSPT.D}$ This output signal confirms that the power supply is delivering power at the programmed setpoint. The $\overline{XSPT.D}$ output is a signal FET switch referenced to *POWCOM*. The switch will "sink" 500 mA to drive most relays and will withstand 60 V open circuit. There is a 1-W, 57-V zener diode from the $\overline{XSPT.D}$ connection to *POWCOM*; this zener absorbs relay energy and protects the FET. To develop a logic output, place a resistor (5 kΩ minimum) between *pin 2* and $\overline{XSPT.D}$.

pin 7. $\overline{INTLK.D}$ This input signal is a secondary off command that disables the unit in the event of a high logic level in the interlock line. The interlock line is typically connected by the user to a safety switch, or a series of safety switches, referred to as an interlock string. These switches protect people, process, and equipment.

With the interlock string incomplete, the power supply's main contactor will not close. If the contactor is closed, and interlock is broken, the output power is disabled within 1 ms. On the PE front panel an **INTERLOCK** status indicator flashes when the interlock string is broken. To reset the **INTERLOCK** indicator, the interlock must be satisfied.

Circuit Specifications
The interlock circuitry has an internal 10 kΩ pull-up resistor to 15 V.

pin 8. unassigned

pin 9. SIGCOM. This signal is a dedicated ground that returns to the internal system ground, then the chassis ground, and finally to the safety ground. All analog connections are referenced to *SIGCOM*.

pin 10. unassigned

pin 11. XI.A This output signal provides a fully buffered 0-5 V dc signal representing full-scale output current of 4.62 A. The output impedance of the *XI.A* output is 100 Ω.

pin 12. XP.A This output signal provides a fully buffered 0-5 V dc signal representing full-scale output power. The output impedance of the *XP.A* output is 100 Ω.

pin 13. XSIG.A+ This input signal and *XSIG.A-* (*pin 5*) provide a differential pair that can be used to linearly control the output power of the supply. This control point is active when the **REMOTE/LOCAL** switch on the front panel (units built after Feb. 1989) OR the DIP switch on the logic board (units built prior to Feb. 1989) is in the **REMOTE** position. See page 4-3 for more information on selecting remote control. A 0-5 V dc input provides linear control from 0 W to full power. The impedance of these inputs is 1 MΩ. The common mode range is 0-10 V.

pin 14. XOFF.D This input signal duplicates the **OFF** function of the front panel **OUTPUT ON/OFF** switch. A high logic level overrides all other commands and forces the output off, opening the main contactor, and resetting any interlock or overtemperature faults.

Circuit Specifications
The *XOFF.D* circuitry has an internal 10 kΩ pull-up resistor to 15 V. Circuit delay is less than 1 ms. While *XOFF.D* is active, only the **REMOTE** or **LOCAL** status indicator will light.

pin 15. $\overline{XSON.D}$ This input signal replaces the **ON** function of the front panel **OUTPUT ON/OFF** switch when the **REMOTE/LOCAL** switch on the front panel (units built after Feb. 1989) OR the DIP switch on the logic board (units built prior to Feb. 1989) is in the **REMOTE** position. See page 4-3 for more information on selecting remote control. A low logic level turns the supply on. *XOFF.D* must be low for $\overline{XSON.D}$ to be active. For information on two-pin and three-pin wiring, see page 3-9.

Circuit Specifications
The $\overline{XSON.D}$ circuitry has an internal 10 kΩ pull-up resistor to 15 V. While $\overline{XSON.D}$ is active, the main contactor remains closed, and the front panel **OUTPUT** status indicator lights.

PART II

OPERATING YOUR PE SERIES GENERATOR

PART II

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SETTING UP

Unpacking

Unpack and inspect your power supply carefully. Check for obvious physical damage to the exterior of the unit, and then remove the six phillips screws on the top cover of the supply.

Remove the top sheet metal to uncover the plexiglass safety shield. Without removing the safety shield, check for obvious signs of physical damage to the interior of the unit.

If no damage is apparent, reinstall the top sheet metal cover and proceed with the unit connections. If you do see signs of shipping damage, contact Advanced Energy Industries, Inc., and the carrier immediately. Save the shipping container for submitting necessary claims to the carrier.

Connecting Input Power

The PE 2500 requires 208-V, single-phase, 50/60 Hz input power.

To connect the input, place the input circuit breaker in the **OFF** position and attach the line cord to the 208-V, single-phase with ground.

Attach the ground stud (next to power cord) to the system ground with at least 14 gauge, stranded wire.

Once the connections are complete, lethal voltages are potentially present at the output connector. Be sure this connector is terminated and follow normal safety precautions when the system is operating.

Connecting Output Power

The main power output connector requires a standard HN plug. A typical combination is an Amphenol part #83-804 (Mil UG59B) and RG-8 cable or Amphenol part #8125 (Mil UG494) and RG 217 cable. There is no practical limit to the length of the cable. Use the following instructions to prepare the cable:

1. Strip the cable; be careful not to nick the braid, the dielectric, or the conductor.
2. Slip end "A", insulator "B", washer "C", and cone "D" onto the cable. Push cone "C" all the way onto the outer insulation. Cut the braided shield 0.25 in. from the cone.
3. Roll the braided shield back over cone "D". Cut the inner insulation and the center conductor to the dimensions shown.
4. Solder the tip to the center conductor.
5. Attach the outer cover.
6. Conduct a high-potential test for the insulation. Hi-pot the insulation to 3 kV dc between the center conductor and the outside shield.

When conducting a high-potential test, high voltages are present. Use extreme caution.

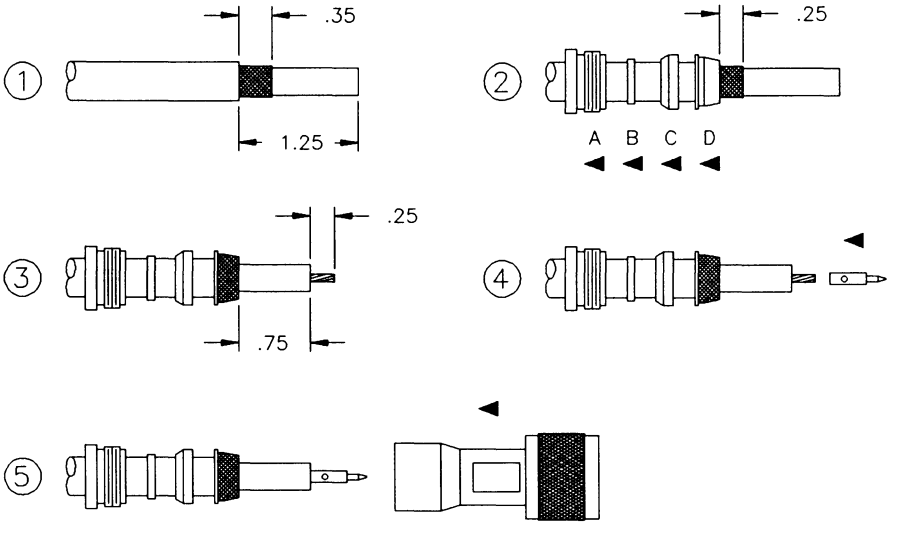

Figure 3-1. Preparing the RG-8 coaxial cable.

The unit is shipped with a dc-blocking capacitor in series with the center lead of the output connector. The capacitor is rated for full-output current and 400 V of dc bias or self bias of either polarity. The output connector shield is normally shipped grounded via a ground strap on the inside of the connector. If a floating output is required, this ground strap may be removed.

Connecting the User I/O Interface

The I/O connector attached to the rear of the supply is internally wired to allow preliminary operation from the front panel. Plug this connector into the 15-pin D connector at the rear of the unit. Figure 3-2 shows the rear panel.

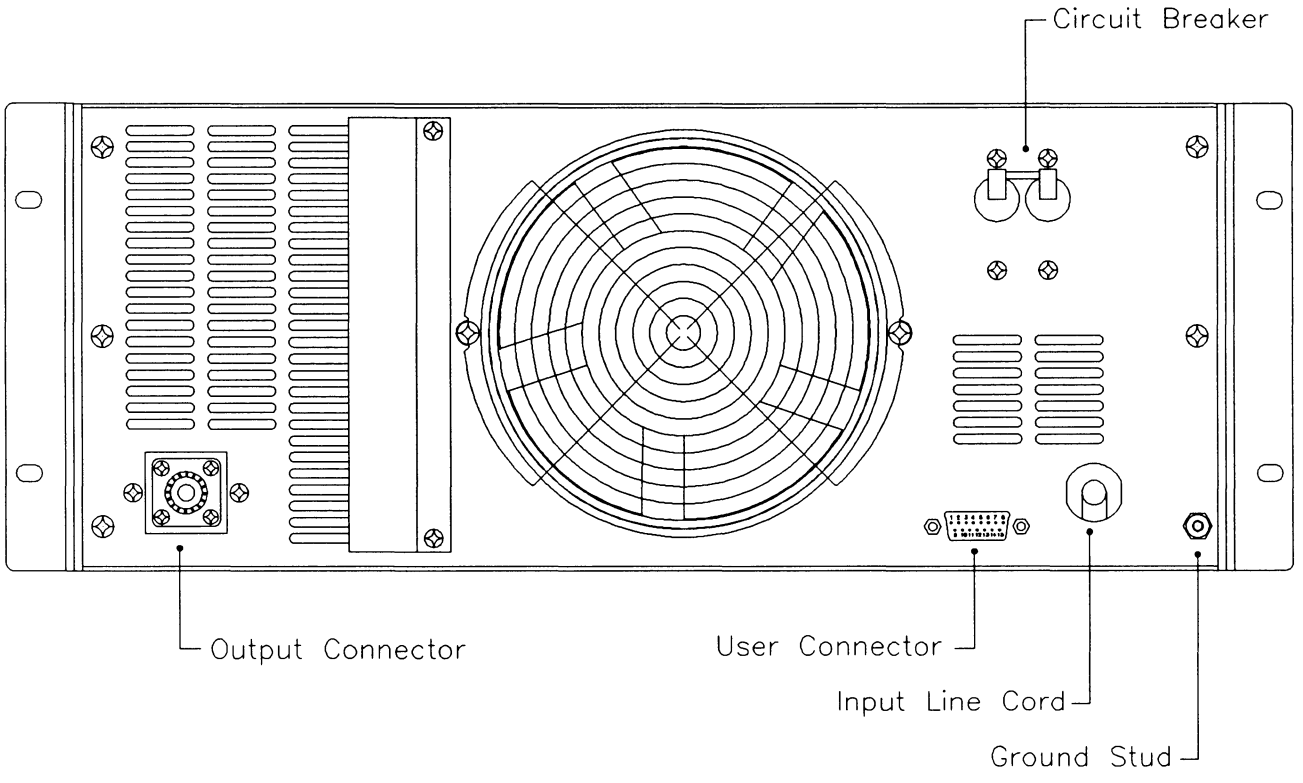

Figure 3-2. Rear panel.

FIRST-TIME OPERATION

Selecting Two-wire or Three-wire Control

You can select either a two-wire or a three-wire configuration for controlling the **output on/off** in remote mode. In the two-wire configuration, *XOFF.D* (pin 14) and $\overline{\text{XSON.D}}$ (pin 15) function as one input; in the three-wire configuration they function independently. For information on selecting remote mode, see the Choosing Modes section on page 4-3.

Both $\overline{\textit{XSON.D}}$ and *XOFF.D* are pulled up through a 10 kΩ resistor, so an open circuit is a sufficient high-logic level. A contact closure to POWCOM is a sufficient low-logic level.

As a safety feature, the **OUTPUT ON/OFF** switch on the front panel will turn the output off while the unit is operating in remote mode. If you use three-wire control, the output remains off until you turn it on again. However, if you use two-wire control, the front panel OUTPUT ON/OFF switch keeps the output off only as long as you hold the switch in the **OFF** position.

Two-wire control

In a two-wire configuration, a closed contact switch pulls both $\overline{\textit{XSON.D}}$ and *XOFF.D* low and turns the output on. An open switch pulls both $\overline{\textit{XSON.D}}$ and *XOFF.D* high and turns the output off. Figure 3-3 shows the wiring diragram for two-wire control.

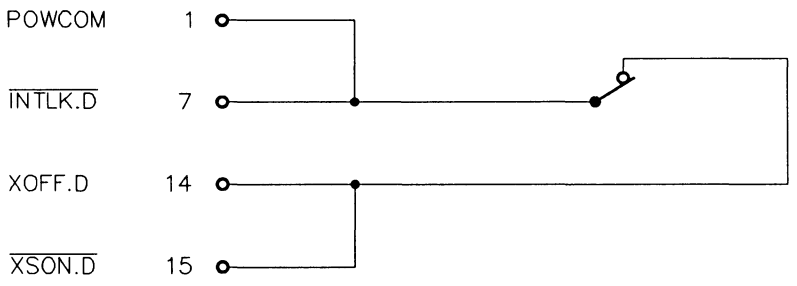

Figure 3-3. Wiring diagram for two-wire control.

Three-wire control

In a three-wire configuration, the momentary contact switch between *XOFF.D* and *POWCOM* is normally closed and the momentary contact switch between *XSON.D* and *POWCOM* is normally open. Fig. 3-4 shows the wiring diragram for three-wire control.

When you first turn the **POWER** switch to **ON**, the output is off; a momentary contact closure between *XSON.D* and *POWCOM* turns the output on. When the output is on, a momentary open contact between *XOFF.D* and *POWCOM* turns the output off.

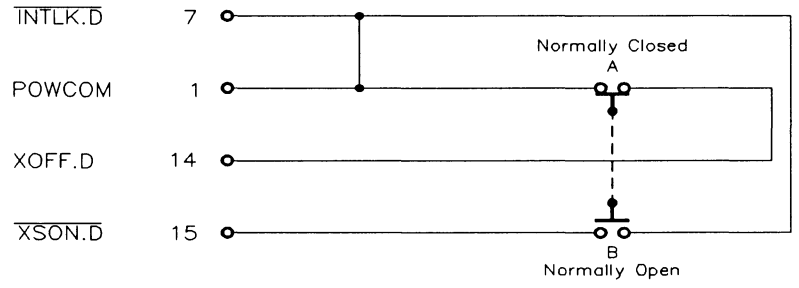

Figure 3-4. Wiring diagram for three-wire control.

Switch Options for Three-Wire Control

To control **output on/off** in remote control, you can use either one 3-position, double-pole switch, or two 2-position, single-pole switches.

Fig. 3-5 shows the wiring diagram for the three-position switch. Table 3-1 shows the output states that result from the three possible switch positions. As shown in Table 3-1, you turn the output on by making momentary contact at switch B, thus closing the circuit between $\overline{XSON.D}$ and *POWCOM*. You turn the output off by making momentary contact at switch A, thus opening the circuit between *XOFF.D* and *POWCOM*. The stable (middle) position maintains the normal contact positions and the unit remains on or off depending on what you most recently selected.

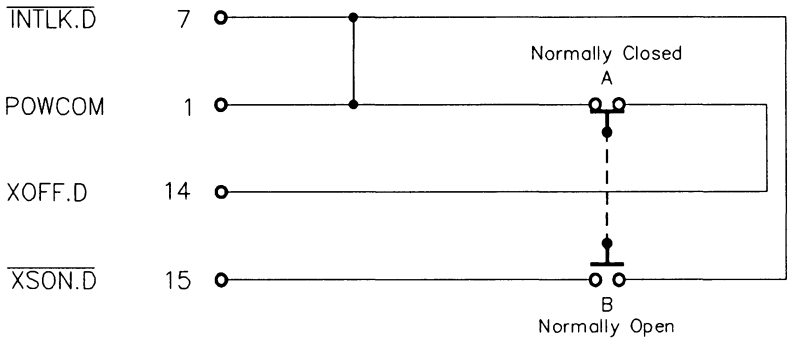

Figure 3-5. Wiring diagram for three-position, double-pole switch.

Table 3-1. Truth table for one 3-position switch showing switch contact states and resulting power output state.

Switch Position	Switch Position State	Switch A Contact State	Switch B Contact State	Power Output State
1	momentary contact	closed	closed	on
2	stable	closed	open	last state selected
3	momentary contact	open	open	off

Fig. 3-6 shows the wiring diagram for the two 2-position switches. Table 3-2 shows the output states resulting from the four possible combinations of the switch position states. As with the three-position switch, momentary contact at switch B closes the circuit between $\overline{XSON.D}$ and *POWCOM* and turns the output on. Momentary contact at switch A opens the circuit between *XOFF.D* and *POWCOM* and turns the output off.

However, pulling $\overline{XSON.D}$ low turns the output on only if the momentary contact switch between *XOFF.D* and *POWCOM* is in its normal position (closed). Therefore, if both switches are held in their momentary positions, the off switch overrides the on switch.

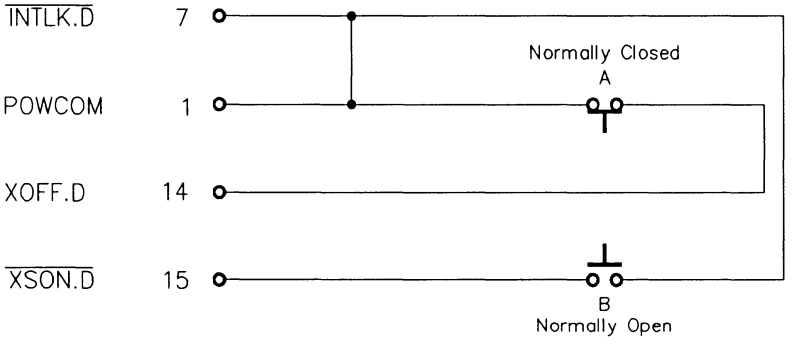

Figure 3-6. Wiring diagram for two 2-position, single-pole switches.

Table 3-2. Truth table for two 2-position switches showing the power output states that result from the four possible combinations of the switch contact states.

Possible Switch Combination	Switch A Position State (Contact State)	Switch B Position State (Contact State)	Power Output State
1	momentary (open)	stable (open)	off
2	stable (closed)	momentary (closed)	on
3	momentary (open)	momentary (closed)	off
4	stable (closed)	stable (open)	last state selected

Selecting Tap Numbers and Establishing Setpoint

The PE internal load-matching transformer contains ten taps. These taps allow the PE to transfer power efficiently to a wide range of loads. The taps provide the following matching capabilities:

Tap	Turns Ratio	Load Impedance Range (Ohms)	Load RMS Voltage Range at full power (1700 W)*
10	1 to 2.53	1006.4 - 696.19	1308 - 1087.9
9	1 to 2.18	747.33 - 516.98	1127.15 - 937.48
8	1 to 1.88	556.43 - 384.92	972.59 - 808.92
7	1 to 1.62	414.29 - 286.59	839.22 - 698.00
6	1 to 1.40	308.46 - 213.38	724.15 - 602.29
5	1 to 1.21	229.67 - 158.87	624.85 - 519.70
4	1 to 1.04	171.00 - 118.29	539.16 - 448.43
3	1 to .90	127.32 - 88.07	465.23 - 386.94
2	1 to .76	94.80 - 65.58	401.44 - 333.88
1	1 to .67	70.58 - 48.82	346.39 - 288.10

* NOTE: Your can read the load rms voltage on the displayMONITOR.

Use the following procedure to determine the proper tap number and establish the setpoint:

Never change the tap number while the output power is enabled. Changing tap settings while applying output power damages the power supply.

1. Turn the **POWER** switch **OFF** and set the **LEVEL** knob fully counterclockwise.

2. Select **TAP NUMBER 1**.

3. Turn the circuit breaker and the **POWER** switch to **ON**.

At this time, the display **MONITOR**, and the **LOCAL** and **INTERLOCK** status indicators should light. If the **REMOTE** indicator lights instead of the **LOCAL** indicator, see the Troubleshooting section on page 5-7. If the **INTERLOCK** status indicator fails to light, check to confirm that the interlock string is satisfied.

4. Move the **OUTPUT ON/OFF** rocker switch momentarily to **ON**. You should hear a contactor close, and the **OUTPUT** status indicator should light.

5. Move the **LEVEL** knob clockwise until the **MONITOR** reads approximately 10% of full output (170 W). The **PLASMA** and **SETPOINT** status indicators should light.

6. To check the output voltage or current, move the **DISPLAY** rocker switch to either the **VOLTAGE** or **CURRENT** setting.

7. Make sure the **SETPOINT** status indicator is lit. Gradually advance the **LEVEL** control knob to the desired power level.

   If the **SETPOINT** indicator light flashes before you reach the desired power level, turn off the supply and increase the **TAP NUMBER** by one setting. Slowly increase the power until you reach the desired power level or the **SETPOINT** indicator light flashes. Repeat this process until you reach operating power without the **SETPOINT** light flashing.

   NOTE: If the SETPOINT indicator light flashes in tap 1, and when you change to tap 2 the light continues flashing and the power level drops, the load impedance is too low to deliver power to the load. Contact AE Customer Service for assistance.

   If you reach tap 7, and you cannot obtain the operating power level before the SETPOINT indicator light flashes, check the output voltage. If the output voltage is greater than 1200 V, the load impedance is too high for the power supply to deliver power to the required load. Contact AE Customer Service.

8. Increase the power 10% over the desired power level. If the **SETPOINT** light does not flash you have the correct **TAP NUMBER**. If the **SETPOINT** light does flash increase the **TAP NUMBER** by one.

9. When you reach the desired power level, lock the **LEVEL** control knob by turning the locking skirt clockwise. The supply can be turned off and on, and the power will return to setpoint automatically.

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REMOTE CONTROL

For units built prior to 2/6/89

1. Before removing the plastic safety shield, turn off the supply and let it sit for 5 min. before beginning work.

2. Unscrew the six phillips screws from the top of the power supply and remove the metal cover.

3. Remove the plastic plexiglass safety shield.

4. Three small DIP switches will be visible on the logic board (with the supply facing forward, the logic board faces the left side of the supply). The left switch controls the **output on/off**, the middle switch controls the **REMOTE** and **LOCAL** indicators on the **STATUS** display, and the right switch controls the signal source for programming power level. "Up" or C1 is for local operation and "down" or C2 is for remote operation. The DIP switches may be set in any combination. After adjusting the switches, replace the plexiglass cover.

For units built after 2/6/89

1. Turn the **OUTPUT ON/OFF** switch **OFF**.

2. For remote operation of the output power, use a standard screwdriver to rotate the adjustable switch located directly under **OUTPUT ON/OFF** switch on the front panel to **REMOTE**.

3. For remote operation of the signal for programming power level, rotate the switch located directly under the **LEVEL** knob on the front panel to **REMOTE**.

If either of the **LOCAL/REMOTE** switches are in the **REMOTE** position, the **LOCAL** indicator light in the **STATUS** display turns off and the **REMOTE** indicator lights.

PART III

SERVICING YOUR PE SERIES GENERATOR

CALIBRATION AND TROUBLESHOOTING

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- Maximum Power 5-5

Troubleshooting 5-7

CALIBRATION

Removing the Top Cover of the Supply

Unscrew the six phillips screws from the top of the power supply and remove the metal cover.

Zeroing the Display Monitor

The screws used to make the zeroing adjustment are accessible through the holes in the plexiglass cover. **P ZERO** = Power Monitor; **V ZERO** = Voltage Monitor; **I ZERO** = Current Monitor

1. Before making any zeroing adjustments, turn the **POWER ON/OFF** switch to **ON**, turn the **OUTPUT ON/OFF** switch to **OFF**, and remove the metal cover. Leave the plexiglass cover in place and let the supply sit for at least 3 min.

2. For each value, turn the appropriate screw adjustment using a small standard screwdriver until the front panel display monitor reads zero.

3. Replace the top cover and the six screws.

Maximum Power

The maximum power adjustment clamps the output power to a predetermined limit, independent of local or remote programming. The **MAX PWR** potentiometer is accessible through the holes on the plexiglass cover.

1. Using the **LEVEL** knob on the front panel or the appropriate user I/O signal to set the power to just above the maximum desired operating level.

2. While operating at this level, turn the control **MAX PWR** potentiometer counterclockwise until the displayed power is at the desired clamp point.

TROUBLESHOOTING GUIDE

All servicing functions involving input and output connections can expose you to lethal voltages. Make sure you take proper safety precautions before you troubleshoot the power supply.

These troubleshooting suggestions are included for your convenience. They are only intended to deal with minor problems. If these troubleshooting tips fail to correct problems with the operation of the power supply, please contact the Advanced Energy Industries, Inc. Customer Service Department at:

(303) 221-4670

or at AE's 24 hour service hotline:

(303) 221-0108

Symptom	Things To Check/Remedy
No front panel lights	Make sure the input power cord is connected to appropriate power source. See the Connecting Input section on page 3-5 for appropriate power source/requirements. Make sure the circuit breaker on the rear of the power supply is **ON**. Make sure the front panel **POWER** switch is **ON**.

No **STATUS** lights except **REMOTE** or **LOCAL**.	Make sure the I/O connector on the rear panel is connected. Make sure the pin connections for the I/O plug are correct. See page 2-13 for on explanation of *XOFF (pin 14)*.
INTERLOCK light is flashing.	Check to see if interlock string is complete. If not, see page 2-12 (*pin 7*) for an explanation of the interlock string requirements.
Output of power supply won't turn on.	Check the first two troubleshooting suggestions (No front panel lights and No **STATUS** lights except **REMOTE** or **LOCAL**). If output still won't come on, make sure the **REMOTE/LOCAL** status indicators on front panel are in the desired positions. See the Remote Control section on page 4-3.
No **PLASMA** indication on **STATUS** display.	Make sure the output cable is attached to the rear of the supply. Make sure the vacuum system is at desired pressure. Make sure the correct power level is programmed into the supply. If not, use the **LEVEL** knob or user I/O interface to set the power level to the desired setpoint. See the First Time Operation section beginning on page 3-9. Verify the voltage output indicated on the **MONITOR** display.
Cannot achieve desired power level, but neither the **ARC** or **SETPOINT** indicators on **STATUS** display are flashing.	Make sure the maximum power adjustment is set correctly. See the Maximum Power section on page 5-5.

Cannot achieve full output power and **ARC** and **SETPOINT** indicators on **STATUS** display are flashing.	Disconnect output cable from power supply and enable the output. If the **ARC** indicator is still flashing, call AE Customer Service.
	Check the system or chamber for low impedance to ground. If a low impedance to ground is present, the problem must be corrected before the supply will function properly. Reconnect the power supply to the system. Turn **OUTPUT** switch **ON**. If the **ARC** indicator is still flashing, lower the power level by 20%. After lowering the power level, if the **ARC** indicator is no longer flashing, see the Selecting Tap Numbers section on page 3-13. If the **ARC** indicator is still flashing, call AE Customer Service.
Cannot achieve full power and **SETPOINT** indicator on **STATUS** display is flashing.	Move the **DISPLAY** switch on the front panel to **VOLTAGE**. If the voltage displayed on the **MONITOR** is above or below the voltage range specified on page 3-13, see the Selecting Tap Numbers section on page 3-13. If the voltage is within the voltage range specified on page 3-13, call AE Customer Service.
OVERTEMP indicator on **STATUS** display is flashing.	Make sure fans are operating and not blocked. Turn the supply off and call AE Customer Service.

PART IV

LEARNING MORE ABOUT YOUR PE GENERATOR

GROUNDING

Current seeks the path of lowest resistance. If several paths are characterized by similar impedances, the current flow may randomly switch paths. This switching may appear as oscillations and cause interference ("noise") with electronic equipment. The goal in any system design is to provide a known, fixed, lowest impedance path. The way to do this is to provide good grounding.

Grounding is important for a variety of reasons:

- it ensures safety of personnel
- it protects equipment
- it is necessary for agency approvals
- it prevents electromagnetic radiation
- it prevents electromagnetic interference
- it provides a known reference for control signals

Grounding requirements and standards are set and promulgated by various commercial and governmental agencies. Information is available from UL, CSA, VDE, FCC, IEEE, SAE, CISPR, and many local government agencies. Always check whatever documents are mandated by your local authorities. This note is intended to provide a broad overview of grounding issues and considerations.

AC and DC Grounding

In the real world there is a significant difference between the techniques used to provide a good dc ground and those used to provide a good ac ground. Just because a system has a very low dc resistance to earth-ground does not at all imply that it has a good ac earth-ground, or vice versa. A dc ground connection requires conductors and connectors with adequate cross-sectional area for the current to be carried; these conductors and connectors must also be made of material with very little resistance.

An ac ground requires conductors and connectors with adequate surface area for the current to be carried; however, the conductors and connectors must also have very little inductive reactance or capacitive reactance to ensure the lowest possible impedance. This becomes more critical as the frequency increases into the RF range.

The major safety issue concerning improperly grounded equipment is that people can come in contact with dangerous voltages. Although this danger is usually viewed as being caused by dc or 50/60 Hz ac voltages, this is not necessarily the case. The multimeter is a typical measuring instrument used to determine whether or not a system or component is grounded. A multimeter is designed to measure dc voltage and current, ac voltage and current, and resistance. However, it is not sensitive to high-frequency energy and often will not even detect the presence of RF energy, much less give accurate readings. ***Since RF can be present without being detected by common means, there is a significant potential for harm to personnel from RF surface burns, arcs that penetrate the skin, and other such injuries.***

Equipment designed to measure RF energy is expensive and bulky, and must be calibrated over narrow frequency ranges. Most facilities do not have this kind of equipment on hand. It is therefore very important that all appropriate personnel (those involved in design, installation, maintenance, and operations) are knowledgeable about all aspects of grounding for electrical energies, from dc through RF.

DANGER! Operating and maintenance personnel must have the correct training before setting up and maintaining high-energy electrical equipment.

While significant numbers of RF problems are caused by improper grounding of RF power supplies used in a process, all plasma systems produce some RF energy that must be taken into acount when the system is designed. As examples: Plasma arcs are like small lightening bolts that cause broad-band RF interference; a plasma chamber is a type of oscillator and radiates RF energy if not shielded; electric motors/relays/solenoids can produce RF energy when they are actuated; even microcomputers used in instruments and controllers can produce RF energy that can cause problems with other circuits. Each one of these sources may interfere with the proper operation of electronic instruments and controls within the system. In the worst cases, this energy can cause noise in equipment at some distance from the source, often hundreds of feet or more away.

Symptoms of Noise Problems

Some grounding problems are inevitable in complex and high-power systems. A good system developer understands grounding problems and, therefore, has a development lab with good earth grounds. This ensures that the new system works well during construction and testing. However, a common occurence is that when it is installed at a customer's site, nothing works. This is typically due to poor earth-grounding techniques.

Similarly, noise problems will not always surface during the development phase of the components that will be used in the system. This is because a manufacturer cannot simulate the exact environment in which the components (power supplies, for instance) will be used. Noise problems tend not to show up until the component is installed and operating in its intended environment. Then, after a few minutes or hours of normal operation, the system finds itself someplace out in left field. Inputs are ignored and outputs are gibberish. The system may respond to a reset, or it may have to be turned off and then back on again, at which point it commences operating as though nothing had happened. There may be an obvious cause, such as an electrostatic discharge from somebody's finger to a keyboard, or the upset occurs every time another machine is turned on or off. Or there may be no obvious cause, and nothing the operator can do will make the upset repeat itself. But a few minutes, or a few hours, or a few days later it happens again.

One symptom of electrical noise problems is randomness, both in the occurrence of the problem and in what the system does in its failure. All operational upsets that occur at seemingly random intervals are not necessarily caused by noise in the system. Marginal bus voltages, inadequate decoupling, rarely encountered software conditions, or timing coincidences can produce upsets that seem to occur randomly. On the other hand, some noise sources can produce upsets downright periodically. Nevertheless, the more difficult it is to characterize an upset as to cause and effect, the more likely it is to be a noise problem.

Types and Sources of Electrical Noise

The name given to electrical noises other than those that are inherent in the circuit components (such as thermal noise) is EMI: electromagnetic interference. Motors, power switches, fluorescent lights, electrostatic discharges, etc., are sources of EMI. There is a veritable alphabet soup of EMI types, and these are briefly described below.

Supply Line Transients

Anything that switches heavy current loads on to or off of ac or dc power lines will cause large transients in these power lines. Switching a vacuum pump on or off, for example, can put a large voltage spike onto the ac power lines.

The basic mechanism behind supply line transients is shown in Fig. 1. The battery represents any power source, ac or dc. The coils represent the line inductance between the power source and the switchable loads R1 and R2. If both loads are drawing current, the line current flowing through the line inductance establishes a magnetic field of some value. Then, when one of the loads is switched off, the field due to that component of the line current

collapses, generating transient voltages, v = L(di/dt), which try to maintain the current at its original level. That's called an "inductive kick." Because of contact bounce, transients are generated whether the switch is being opened or closed, but they're worse when the switch is being opened.

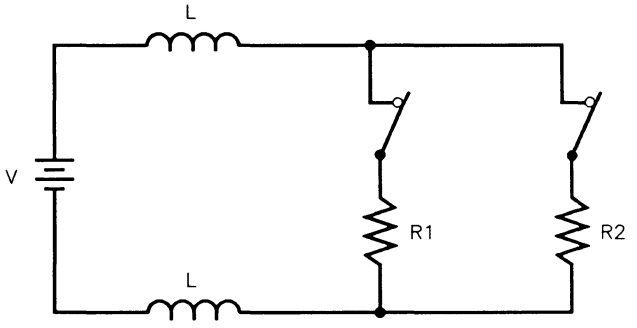


Figure 1. Supply line transients.

An inductive kick of one type or another is involved in most line transients. Other mechanisms for line transients exist, involving noise pickup on the lines. The noise voltages are then conducted to a susceptible circuit right along with the power.

EMP and RFI

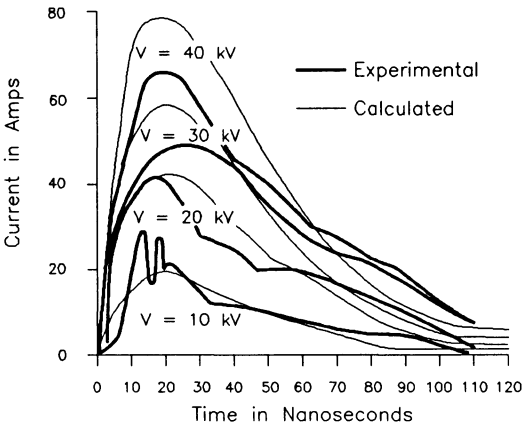
Anything that produces arcs or sparks will radiate electromagnetic pulses (EMP) or radio-frequency interference (RFI). Spark discharges have probably caused more software upsets in digital equipment than any other single noise source. The upsetting mechanism is the EMP produced by the spark. The EMP induces transients in the circuit, which are what actually cause the upset.

Arcs and sparks occur in plasma chambers, electron-beam systems, and magnetron sputtering systems; in associated equipment such as electric motors and switches; and in static discharges. Electric motors that have commutator bars produce an arc as the brushes pass from one bar to the next. Dc motors and the "universal" (ac/dc) motors that are used to power hand tools are the kinds that have commutator bars. In switches, the same inductive kick that puts transients on the supply lines will cause an opening or closing switch to throw a spark. Vacuum systems contain vacuum pumps, solenoid valves, motors, power supplies, and many other noise producers.

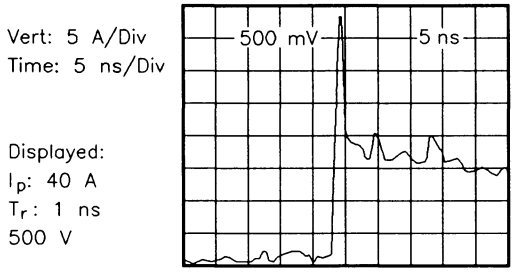
ESD

Electrostatic discharge (ESD) is the spark that occurs when a person picks up a static charge from walking across a carpet, and then discharges it into a keyboard, or whatever else can be touched. Walking across a carpet in a dry climate, a person can accumulate a static voltage of 35 kV. The current

pulse from an electrostatic discharge has an extremely fast rise time — typically, 4 A/nsec. Figure 2 shows ESD waveforms that have been observed by some investigators of ESD phenomena.



(a)



(b)

Figure 2. Waveforms of electrostatic discharge currents from a hand-held metallic object.

It is enlightening to calculate the L(di/dt) voltage required to drive an ESD current pulse through a couple of inches of straight wire. Two inches of straight wire has about 50 nH of inductance. That's not very much, but using 50 nH for L and 4 A/nsec for di/dt gives an L(di/dt) drop of about 200 V. Recent observations by W.M. King suggest even faster rise times (Fig. 2B) and the occurrence of multiple discharges during a single discharge event.

Obviously, ESD sensitivity needs to be considered in the design of equipment that is going to be used in difficult industrial environments. Although humidity is controlled in many IC clean rooms, this is not the case in many other clean rooms. Any time large volumes of air are moved, electrostatic energy will build up. This can cause ESD problems for a

system's control circuitry, whether in the system computer, a power supply's microprocessor, an electronic vacuum pump, or a critical endpoint detector such as an RGA computer.

Ground Noise

Currents in ground lines are another source of noise. These can be 60-Hz currents from the power lines, or RF hash, or crosstalk from other signals that are sharing this particular wire as a signal return line. Noise in the ground lines is often referred to as a "ground loop" problem. The basic concept of the ground loop is shown in Fig. 3. The problem is that true earth-ground is not really at the same potential in all locations. If the two ends of a wire are earth-grounded at different locations, the voltage difference between the two "ground" points can drive significant currents (several amperes) through the wire. Consider the wire to be part of a loop which contains, in addition to the wire, a voltage source that represents the difference in potential between the two ground points, and you have the classical "ground loop." By extension, the term is used to refer to any unwanted (and often unexpected) currents in a ground line.

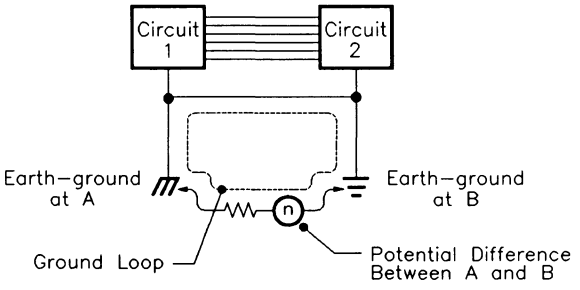


Figure 3. Illustration of a ground loop.

"Radiated" and "Conducted" Noise

Radiated noise is noise that arrives at the victim circuit in the form of electromagnetic radiation, such as EMP and RFI. It causes trouble by inducing extraneous voltages in the circuit. Conducted noise is noise that arrives at the victim circuit already in the form of an extraneous voltage, typically via the ac or dc power lines.

You can defend against radiated noise by carefully designing layouts and using effective shielding techniques. You can defend against conducted noise with filters and suppressors, although layouts and grounding techniques are important here, too.

Types of Failures and Failure Mechanisms

A major problem that EMI can cause in digital systems is intermittent operational malfunction. These software upsets occur when the system is in operation at the time an EMI source is activated, and are usually characterized by a loss of information or a jump in the execution of the program to some random location in memory. The person who has to iron out such problems is tempted to say the program counter went crazy. There is usually no damage to the hardware, and normal operation can resume as soon as the EMI has passed or the source is de-activated. Resuming normal operation usually requires manual or automatic reset, and possibly re-entering of lost information.

Electrostatic discharges from operating personnel can cause not only software upsets, but also permanent ("hard") damage to the system. For this to happen the system doesn't even have to be in operation. Sometimes the permanent damage is latent, meaning the initial damage may be marginal and require further aggravation through operating stress and time before permanent failure takes place. Sometimes the damage is hidden.

Current Loops

The first thing most people learn about electricity is that current won't flow unless it can flow in a closed loop. This simple fact is sometimes temporarily forgotten by the overworked engineer who has spent the past several years mastering the intricacies of the DO loop, the timing loop, the feedback loop, and maybe even the ground loop.

The simple current loop probably owes its apparent demise to the invention of the ground symbol. By a stroke of the pen you avoid having to draw the return paths of most of the current loops in the circuit. Then "ground" turns into an infinite current sink, so that any current that flows into it is gone and forgotten. Forgotten it may be, but it's not gone. It must return to its source, so that its path will by all the laws of nature form a closed loop.

The physical geometry of a given current loop is the key to why it generates EMI, why it's susceptible to EMI, and how to shield it. Specifically, it's the area of the loop that matters.

Any flow of current generates a magnetic field with an intensity that varies inversely to the distance from the wire that carries the current. Two parallel wires conducting currents +I and -I (as in signal feed and return lines) would generate a nonzero magnetic field near the wires if the distance from

a given point to one wire is noticeably different than the distance from the same point to the other wire, but farther away (relative to the wire spacing). Where the distances from a given point to either wire are about the same, the fields from both wires tend to cancel out.

Thus, maintaining proximity between feed and return paths is an important way to minimize their interference with other signals. The way to maintain their proximity is essentially to minimize their loop area. And, because the mutual inductance from current loop A to current loop B is the same as the mutual inductance from current loop B to current loop A, a circuit that doesn't radiate interference doesn't receive it either.

Thus, from the standpoint of reducing both generation of EMI and susceptibility to EMI, the hard rule is to keep loop areas small. To say that loop areas should be minimized is the same as saying the circuit inductance should be minimized. Inductance is by definition the constant of proportionality between current and the magnetic field it produces: $\phi = LI$. Holding the feed and return wires close together so as to promote field cancellation can be described either as minimizing the loop area or as minimizing L. It's the same thing.

Shielding

There are three basic kinds of shields: shielding against capacitive coupling, shielding against inductive coupling, and RF shielding. Capacitive coupling is electric field coupling, so shielding against it amounts to shielding against electric fields. As will be seen, this is relatively easy. Inductive coupling is magnetic field coupling, so shielding against it is shielding against magnetic fields. This is a little more difficult. Strangely enough, this type of shielding does not in general involve the use of magnetic materials. RF shielding, the classical "metallic barrier" against all sorts of electromagnetic fields, is what most people picture when they think about shielding. Its effectiveness depends partly on the selection of the shielding material, but mostly, as it turns out, on the treatment of its seams and the geometry of its openings.

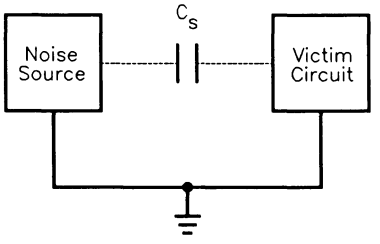
Shielding Against Capacitive Coupling

Capacitive coupling involves the passage of interfering signals through mutual or stray capacitances that aren't shown on the circuit diagram, but which the experienced engineer knows are there. Capacitive coupling to your body is what would cause an unstable oscillator to change its frequency when you reach your hand over the circuit, for example. More importantly, in a digital system it causes crosstalk in multi-wire cables.

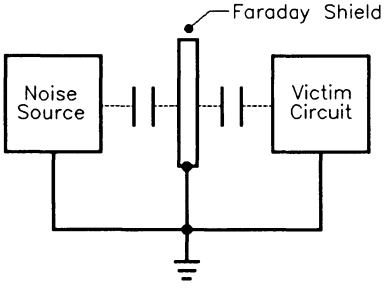
The way to block capacitive coupling is to enclose the circuit or conductor you want to protect in a metal shield. That's called an electrostatic or Faraday shield. If coverage is 100%, the shield does not have to be

grounded, but it usually is, to ensure that circuit-to-shield capacitances go to signal reference ground rather than acting as feedback and crosstalk elements. Besides, from a mechanical point of view, grounding it is almost inevitable.

A grounded Faraday shield can be used to break capacitive coupling between a noisy circuit and a victim circuit, as shown in Fig. 4. Figure 4A shows two circuits capacitively coupled through the stray capacitance between them. In Figure 4B the stray capacitance is intercepted by a grounded Faraday shield, so that interference currents are shunted to ground. For example, a grounded plane can be inserted between PCBs (printed circuit boards) to eliminate most of the capacitive coupling among them.



(a) Capacitive Coupling



(b) Electrostatic Shielding

Figure 4. Use of Faraday shield.

Shielding Against Inductive Coupling

With inductive coupling, the physical mechanism involved is a magnetic flux density B from some external interference source that links with a current loop in the victim circuit, and generates a voltage in the loop in accordance with Lenz's law: $v = NA(dB/dt)$, where in this case $N = 1$ and A is the area of the current loop in the victim circuit.

There are two aspects to defending a circuit against inductive coupling. One aspect is to try to minimize the offensive fields at their source. This is done by minimizing the area of the current loop at the source so as to promote field cancellation, as described in the section on current loops. The other aspect is to minimize the inductive pickup in the victim circuit by minimizing the area of that current loop, since, from Lenz's law, the induced voltage is proportional to this area. So the two aspects really involve the same corrective action: Minimize the areas of the current loops. In other words, minimizing the offensiveness of a circuit inherently minimizes its susceptibility.

Shielding against inductive coupling means nothing more nor less than controlling the dimensions of the current loops in the circuit. We will look at two examples of this type of "shielding": the coaxial cable and the twisted pair.

The Coaxial Cable. Figure 5 shows a coaxial cable carrying a current I from a signal source to a receiving load. The shield carries the same current as the center conductor. Outside the shield, the magnetic field produced by +I flowing in the center conductor is cancelled by the field produced by -I flowing in the shield. To the extent that the cable is ideal in producing zero external magnetic field, it is immune to inductive pickup from external sources. The cable effectively adds zero area to the loop. This is true only if the shield carries the same current as does the center conductor.

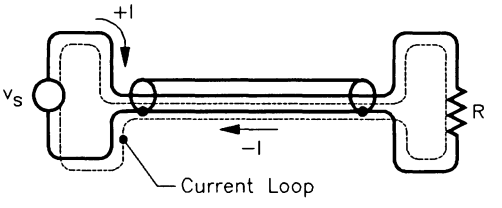
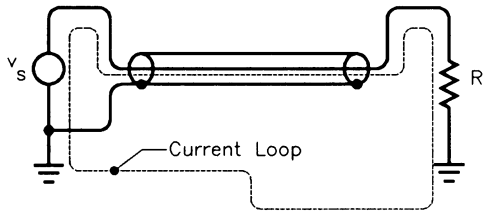


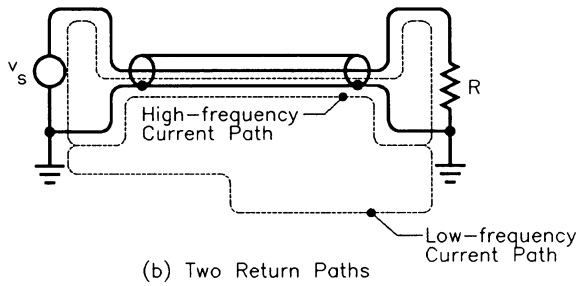
Figure 5. External to the shield, $\phi = 0$

In the real world, both the signal source and the receiving load are likely to have one end connected to a common signal ground. In that case, should the cable be grounded at one end, both ends, or neither end? The answer is that it should be grounded at both ends. Figure 6A shows the situation when the cable shield is grounded at only one end. In that case the current loop runs down the center conductor of the cable, then back through the common ground connection. The loop area is not well defined. The shield not only does not carry the same current as the center conductor, but it doesn't carry any current at all. There is no field cancellation at all. The shield has no effect whatsoever on either the generation of EMI or susceptibility to EMI. (It is, however, still effective as an electrostatic shield, or at least it would be if the shield coverage were 100%.)

Figure 6B shows the situation when the cable is grounded at both ends. Does the shield carry all of the return current, or only a portion of it on account of the shunting effect of the common ground connection? The answer to that question depends on the frequency content of the signal. In general, the current loop will follow the path of least impedance. At low frequencies, 0 Hz to several kilohertz, where the inductive reactance is insignificant, the current will follow the path of least resistance. Above a few kilohertz, where inductive reactance predominates, the current will follow the path of least inductance. The path of least inductance is the path of minimum loop area. Hence, for higher frequencies the shield carries virtually the same current as the center conductor, and is therefore effective against both generation and reception of EMI.



(a) Shield Has No Effect



(b) Two Return Paths

Figure 6. Use of coaxial cable.

Note that we have now introduced the infamous "ground loop" problem, as shown in Fig. 7A. Fortunately, a digital system has some built-in immunity to moderate ground loop noise. In a noisy environment, however, you can break the ground loop and still maintain the shielding effectiveness of the coaxial cable by inserting an optical coupler, as shown in Fig. 7B. What the optical coupler does, basically, is allow you to redefine the signal source as being ungrounded, so that the optically coupled end of the cable need not be grounded; this still lets the shield carry the same current as the center conductor. Obviously, if the signal source weren't grounded in the first place, the optical coupler wouldn't be needed.

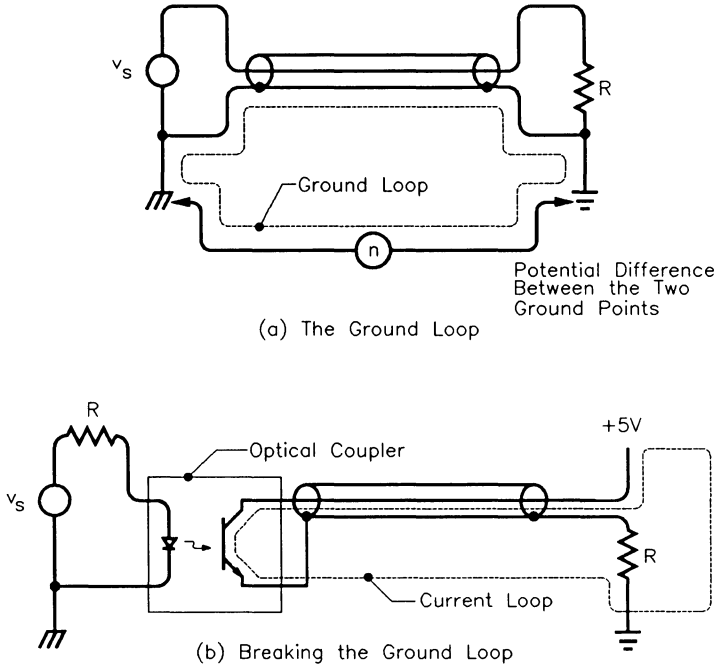


Figure 7. Use of optical coupler.

The Twisted Pair. A cheaper way to minimize loop area is to run the feed and return wires right next to each other. This isn't as effective as a coaxial cable in minimizing loop area. An ideal coaxial cable adds zero area to the loop, whereas merely keeping the feed and return wires next to each other is bound to add a finite area.

However, two things work to make this cheaper method almost as good as a coaxial cable. First, coaxial cables are not ideal. If the shield current isn't evenly distributed around the center conductor at every cross-section of the cable (it isn't), then field cancellation external to the shield is incomplete. Since field cancellation is incomplete, the effective area added to the loop by the cable isn't zero. Second, in the cheaper method the feed and return wires can be twisted together. This not only maintains their proximity, but the noise picked up in one twist tends to cancel out the noise picked up in the next twist down the line. Thus the "twisted pair" turns out to be about as good a shield against inductive coupling as coaxial cable is.

The twisted pair does not, however, provide electrostatic shielding (i.e., shielding against capacitive coupling). Another operational difference is that the coaxial cable works better at higher frequencies. This is primarily

because the twisted pair adds more capacitive loading to the signal source than does the coaxial cable. The twisted pair is normally considered useful up to only about 1 MHz; the coaxial cable is considered useful up to 1 GHz.

RF Shielding

A time-varying electric field generates a time-varying magnetic field, and vice versa. Far from the source of a time-varying EM field, the ratio of the amplitudes of the electric and magnetic fields is always 377 Ω. Up close to the source of the fields, however, this ratio can be quite different, and dependent on the nature of the source. The field where the ratio is near 377 Ω is called the far field, and the field where the ratio is significantly different from 377 Ω is called the near field. The ratio itself is called the wave impedance, E/H.

The near field goes out about one-sixth of a wavelength from the source. At 1MHz this is about 150 ft., and at 10 MHz it's about 15 ft. That means that if an EMI source is in the same room with the victim circuit, it's likely to be a near field problem. The reason this matters is that in the near field an RF interference problem could be almost entirely due to E-field coupling or H-field coupling, and that could influence the choice of an RF shield or whether an RF shield will help at all.

In the near field of a whip antenna, the E/H ratio is higher than 377 Ω, which means it's mainly an E-field generator. A wire-wrap post can be a whip antenna. Interference from a whip antenna would be by electric field coupling, which is basically capacitive coupling. Methods to protect a circuit from capacitive coupling, such as a Faraday shield, would be effective against RF interference from a whip antenna. A gridded-ground structure would be less effective.

In the near field of a loop antenna, the E/H ratio is lower than 377 Ω, which means it's mainly an H-field generator. Any current loop is a loop antenna. Interference from a loop antenna would be by magnetic field coupling, which is basically the same as inductive coupling. Methods to protect a circuit from inductive coupling, such as a gridded-ground structure, would be effective against RF interference from a loop antenna. A Faraday shield would be less effective.

A more difficult case of RF interference, near field or far field, may require a genuine metallic RF shield. The idea behind RF shielding is that time-varying EMI fields induce currents in the shielding material. The induced currents dissipate energy in two ways: I^2R losses in the shielding material and radiation losses as they re-radiate their own EM fields. The energy for both of these mechanisms is drawn from the impinging EMI fields —thus the EMI is weakened as it penetrates the shield.

More formally, the I^2R losses are referred to as absorption loss, and the re-radiation is called reflection loss. As it turns out, absorption loss is the primary shielding mechanism for H-fields, and reflection loss is the primary shielding mechanism for E-fields. Reflection loss, being a surface phenomenon, is pretty much independent of the thickness of the shielding material. Both loss mechanisms, however, are dependent on the frequency (ω) of the impinging EMI field, and on the permeability (μ) and conductivity (σ) of the shielding material. These loss mechanisms vary approximately as follows:

reflection loss to an E-field (in dB) $\sim \log \frac{\sigma}{\omega\mu}$

absorption loss to an H-field (in dB) $\sim t\sqrt{\omega\sigma\mu}$

Where:

t = the thickness of the shielding material.

The first expression indicates that 1) E-field shielding is more effective if the shield material is highly conductive and less effective if the shield is ferromagnetic, and 2) that low-frequency fields are easier to block than high-frequency fields. This is shown in Fig. 8.

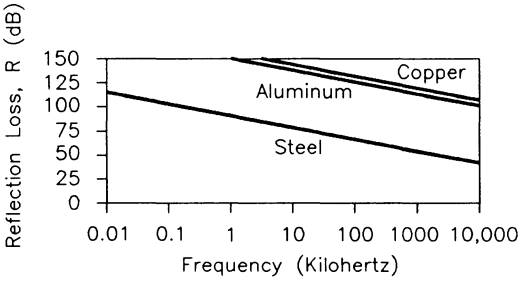


Figure 8. E-field shielding.

Copper and aluminum both have the same permeability, but copper is slightly more conductive, and so provides slightly greater reflection loss to an E-field. Steel is less effective for two reasons. First, it has a somewhat elevated permeability due to its iron content, and, second, as tends to be the case with magnetic materials, it is less conductive.

On the other hand, according to the expression for absorption loss to an H-field, H-field shielding is more effective at higher frequencies and with shield material that has both high conductivity and high permeability. In practice, however, selecting steel for its high permeability involves some compromise in conductivity. But the increase in permeability more than

makes up for the decrease in conductivity, as can be seen in Fig. 9. This figure also shows the effect of shield thickness.

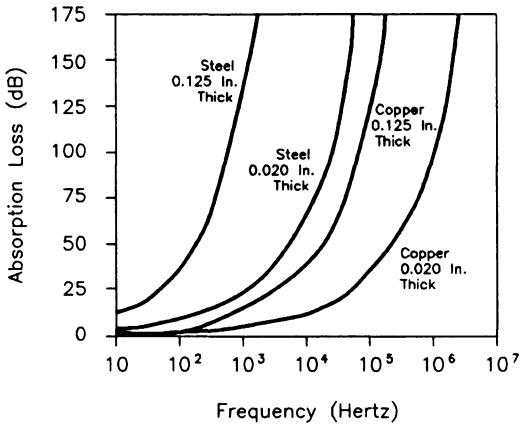


Figure 9. H-field shielding.

A composite of E-field and H-field shielding is shown in Fig. 10. However, this type of data is meaningful only in the far field. In the near field, the EMI could be 90% H-field, in which case the reflection loss is irrelevant. It would be advisable then to beef up the absorption loss, at the expense of reflection loss, by choosing steel. A better conductor than steel might be less expensive, but it would also be ineffective.

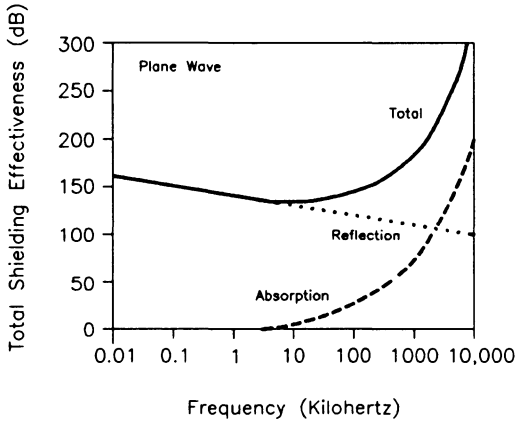


Figure 10. E- and H-field shielding.

A characteristic that can be exploited for low-frequency magnetic fields is the ability of a high-permeability material such as mumetal to divert the field by presenting a very low reluctance path to the magnetic flux. Above a few kilohertz, however, the permeability of such materials is the same as steel.

In actual fact the selection of a shielding material turns out to be less important than the presence of seams, joints and holes in the physical structure of the enclosure. The shielding mechanisms are related to the induction of currents in the shield material, but the currents must be allowed to flow freely. If they have to detour around slots and holes, as shown in Fig. 11, the shield loses much of its effectiveness.

As can be seen in Fig. 11, the severity of the detour has less to do with the area of the hole than it does with the geometry of the hole. Comparing Fig. 11C with Fig. 11D shows that a long narrow discontinuity such as a seam can cause more RF leakage than a line of holes with larger total area. A person who is responsible for designing or selecting rack or chassis enclosures for an EMI environment needs to be familiar with the techniques that are available for maintaining electrical continuity across seams. Information on these techniques is available in the references at the end of this note.

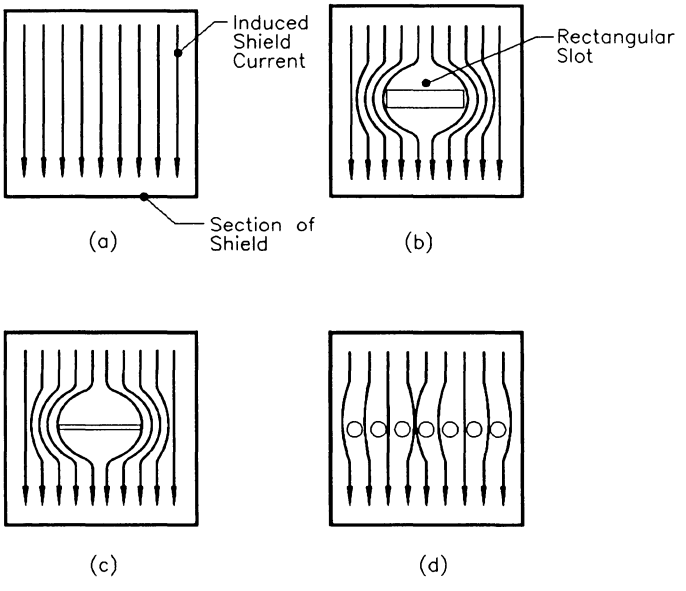


Figure 11. Effect of shield discontinuity on magnetically induced shield current.

Grounds

There are two kinds of grounds: earth ground (safety ground) and signal ground. The earth is not an equipotential surface, so earth-ground potential varies. In addition, its other electrical properties are not conducive to its use as a return conductor in a circuit. However, circuits are often connected to earth ground for protection against shock hazards. The other kind of ground, signal ground, is an arbitrarily selected reference node in a circuit—the node with respect to which other node voltages in the circuit are measured.

Earth Ground

The standard U.S. three-wire, single-phase ac power distribution system is represented in Fig. 12. The white wire is earth-grounded at the service entrance. If a load circuit has a metal enclosure or chassis, and if the black wire develops a short to the enclosure, there will be a shock hazard to operating personnel, unless the enclosure itself is earth-grounded. If the enclosure is earth-grounded, a short results in a blown fuse rather than a "hot" enclosure. The earth-ground connection to the enclosure is called a safety ground. The advantage of the three-wire power system is that it distributes a safety ground along with the power.

Note that the safety-ground wire carries no current, except in case of a fault, so that at least for low frequencies it's at earth-ground potential along its entire length. The voltage of the white wire, on the other hand, may be several volts different than the voltage of ground, due to the IR drop along its length.

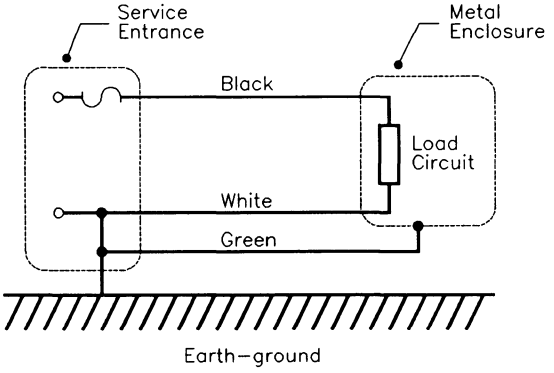


Figure 12. Single-phase power distribution.

In high-power systems and systems that radiate high levels of noise, it is common practice to provide each system with an individual earth-ground. This is done by driving a copper stake or stakes into the ground under or very close to the frame of the system, even to the extent of drilling holes through concrete floors.

In multistory buildings it is even more difficult to provide a low-impedance, secure connection to the earth. Many times this is done by using a copper pipe that provides water to the system. This practice is suspect because the water pipe may travel a considerable distance before making contact with the earth, and thus may have a relatively high impedance/resistance. In a multistory system, a heavy copper strap should connect the system frame to an earth-ground stake by the shortest possible path.

All earth-ground connections should be made with 1-1.5 in. copper strap whenever possible. This practice provides a low-impedance path for both dc and ac.

In many areas the soil is very dry and has high electrical resistance. This is cured by providing a grid of stakes or a mat of copper wires, and a means of continually wetting the earth around the stakes or grid.

In the past, the earth around the ground stake was saturated with copper sulfate. However, the toxicity of copper sulfate combined with its high solubility endangers groundwater supplies, and so this practice is now illegal. Other, nontoxic electrolytes are sometimes used, depending on local laws.

Signal Ground

Signal ground is a single point in a circuit that is designated to be the reference node for the circuit. Commonly, wires that connect to this single point are also referred to as "signal ground." In some circles "power supply common" or PSC is the preferred terminology for these conductors. In any case, the manner in which these wires connect to the actual reference point is the basis of distinction among three kinds of signal-ground wiring methods: series, parallel, and multipoint (shown in Fig. 13).

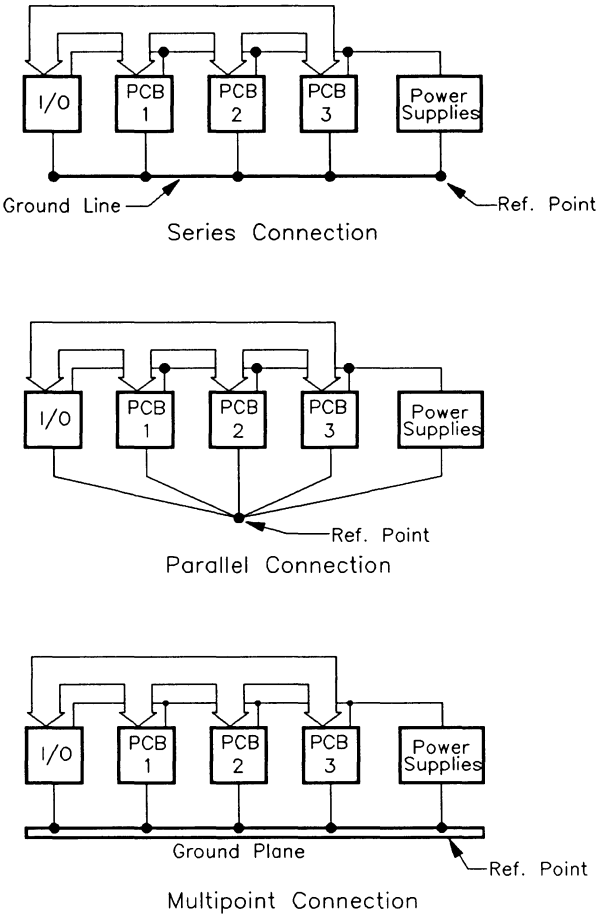


Figure 13. Three ways to wire the grounds.

The series connection is pretty common because it's simple and economical. It's the noisiest of the three, however, due to common-ground impedance coupling between the circuits. When several circuits share a ground wire, currents from one circuit, flowing through the finite impedance of the common ground line, cause variations in the ground potential of the other circuits. Given that the currents in a digital system tend to be spiked, and that the common impedance is mainly inductive reactance, the variations could be bad enough to cause bit errors in high current or particularly noisy situations.

The parallel connection eliminates common-ground impedance problems, but uses a lot of wire. Other disadvantages are that the impedance of the individual ground lines can be very high, and the ground lines themselves can become sources of EMI.

In the multipoint system, ground impedance is minimized by using a ground plane with the various circuits connected to it by very short ground leads. This type of connection would be used mainly in RF circuits above 10 MHz.

Practical Grounding

A combination of series and parallel ground-wiring methods can be used to trade off economic and electrical considerations. The idea is to run series connections for circuits that have similar noise properties, and connect them at a single reference point, as in the parallel method (shown in Fig. 14).

In Fig. 14, the "noisy and high current signal ground" connects to things like motors and relays. The hardware ground is the safety-ground connection to chassis, racks, and cabinets. It's a mistake to use the hardware ground as a return path for signal currents because it's fairly noisy (for example, it's the hardware ground that receives an ESD spark) and tends to have high resistance due to joints and seams.

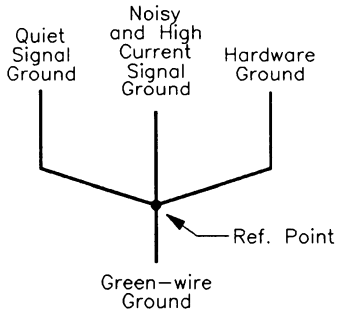


Figure 14. Parallel connection of series grounds.

Screws and bolts don't always make good electrical connections because of galvanic action, corrosion, and dirt. These kinds of connections may work well at first, and then cause mysterious maladies as the system ages.

Figure 15 illustrates a grounding system for a typical power supply setup in a vacuum-process system, showing an application of the series/parallel ground-wiring method. Ground lines 1 and 2 are normally required by code but cannot be relied upon in high-power systems. Ground lines 3, 4, and 5 illustrate series grounding.

Ground lines 6 and 7 illustrate parallel grounding. They ensure that power supply 1 (PS1) and power supply 2 (PS2) are integral parts of the system grounding scheme (the utility connection is usually not a quality ground). Ground line 8 provides the primary system earth-ground connection.

Current return 9 ensures a current return path for the power supply output and should not be confused with the ground lines (1 through 8). See the typical applications discussed on pages 1-9 through 1-16 for instructions on how to connect this line with the earth-ground terminal.

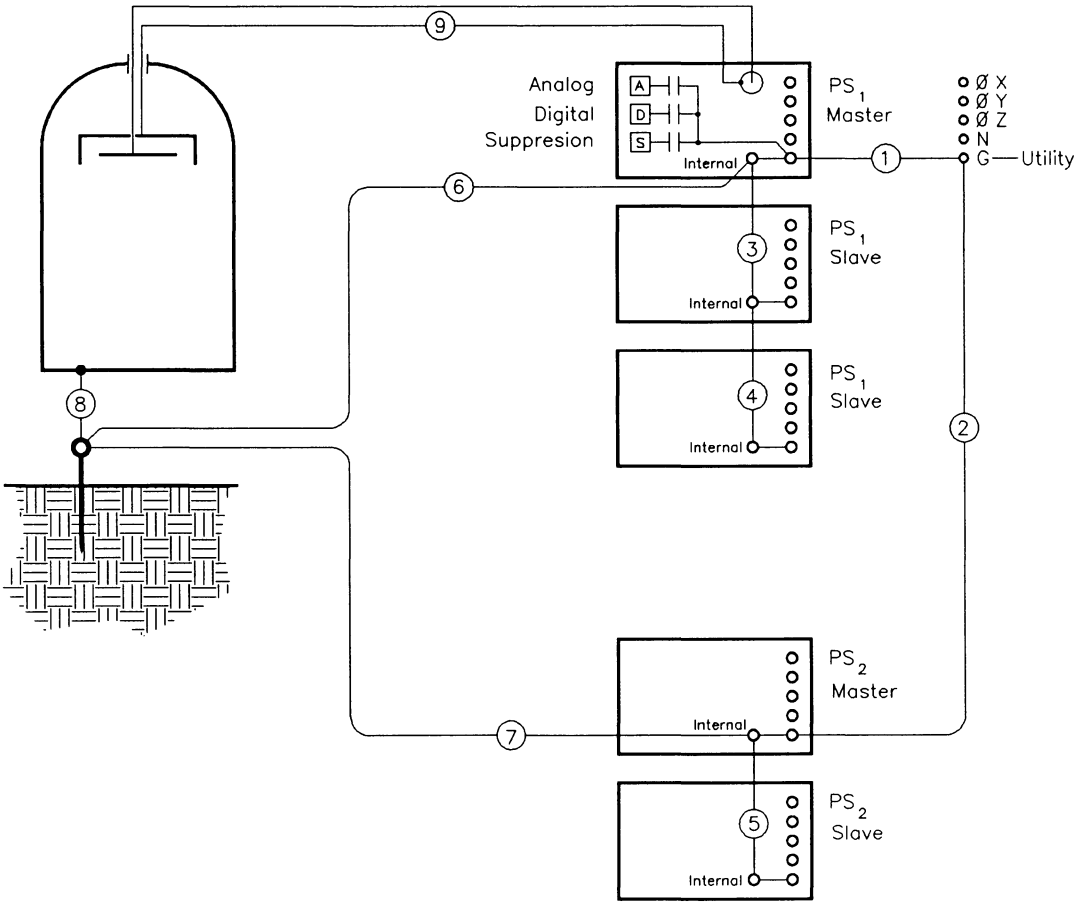


Figure 15. Grounding connections for power supplies in a process system.

The separation of grounds shown in Fig. 16 is similar to what is shown in Fig. 15, but here it is shown at the PCB level. Currents in multiplexed LED displays tend to put a lot of noise on the ground and supply lines because of the constant switching and changing involved in the scanning process. The segment driver ground is relatively quiet, since it doesn't conduct the LED currents. The digit-driver ground is noisier, and should be provided with a separate path to the PCB ground terminal, even if the PCB ground layout is gridded. The LED feed and return current paths should be laid out on opposite sides of the board like parallel flat conductors.

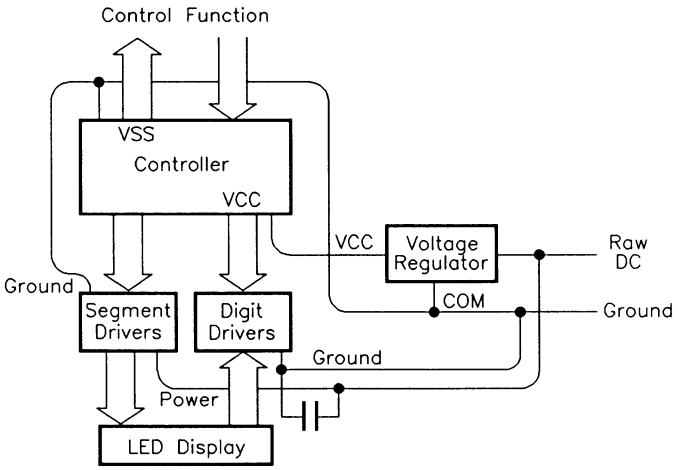


Figure 16. Separate ground for multiplexed LED display.

Figure 17 shows right and wrong ways to make ground connections in racks. Note that the safety ground connections from panel to rack are made through ground straps, not panel screws. Rack 1 correctly connects signal ground to rack ground only at the single reference point. Rack 2 incorrectly connects signal ground to rack ground at two points, creating a ground loop around points 1, 2, 3, 4, 1.

Breaking the "electronics ground" connection to point 1 eliminates the ground loop, but leaves signal ground in rack 2 sharing a ground impedance with the relatively noisy hardware ground to the reference point: In fact, it may end up using hardware ground as a return path for signal and power supply currents. This will probably cause more problems than the ground loop.

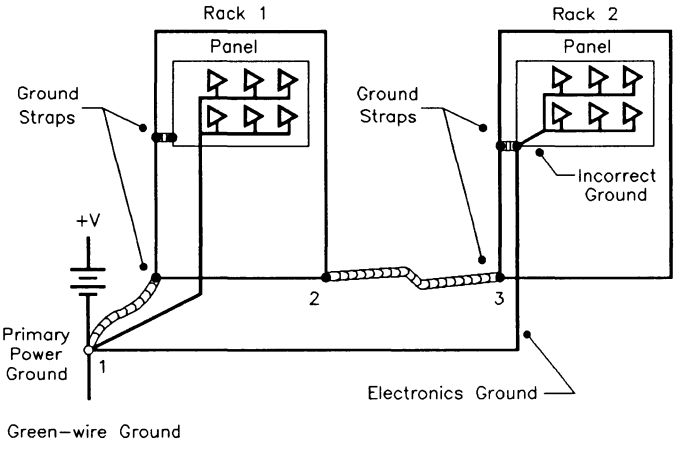


Figure 17. Electronic circuits mounted in equipment racks should have separate ground connections. Rack 1 shows correct grounding; rack 2 shows incorrect grounding.

Braided Cable

Ground impedance problems can sometimes be eliminated by using braided cable. The reduction in impedance is due to skin effect: At higher frequencies the current tends to flow along the surface of a conductor rather than uniformly through its bulk. While this effect tends to increase the impedance of a given conductor, it also indicates the way to minimize impedance—to manipulate the shape of the cross-section so as to provide more surface area. For its bulk, braided cable is almost pure surface.

Depending on the length of the cable and the actual frequencies involved, there may be situations where braided cable is not desirable. The individual strands of wire in the braided cable may present a high inductance to RF and actually impede current flow. For high-power RF applications, it is usually best to use a wide copper strap.

Glossary

Digital ground Data signal ground Analog signal ground	Ground-line connections for nondifferential-input, paired signal wires. These wires are paired for noise-rejection purposes. The ground wire of the pair may be connected to an individual ground connection or to a common ground connection.
Signal common Power common Common return	A return conductor (usually low current) common to several circuits.
RF return	The path or paths that RF energy uses to return to its source (such as an RF generator). RF energy is a surface phenomenon and may travel over the surface of insulated wires, chassis, frames, floors, or equipment faces. Special methods must be used to ensure that there is a solid earth-ground in systems that produce or use RF energy.
Ground Earth ground	A terminal intended to ensure, by means of a special connection, the grounding (earthing) of part of an apparatus when properly connected to an earth electrode.
Grounding conductor	The conductor that is used to establish ground and that connects a piece of equipment or device to the ground electrode.
Ground electrode	A conductor, group of conductors, mat, or grid, in intimate contact with the earth for the purpose of providing a connection with ground. This electrode determines the lowest ground potential for an electrical system.
Ground loop	A potentially detrimental loop formed when two or more points in an electrical system that are normally at ground potential are connected by an additional conducting path.

Earth resistivity	A measurement of the electrical resistance of a unit volume of soil. The common unit of measure is the ohm-meter, which is the resistance measured between faces of a cubic meter of soil by driving ground electrodes into the earth 1 m apart to a depth of 1 m.
Conducted interference	Interference resulting from conducted radio-frequency noise, switching spikes, lightening strikes, or conducted electrical noise (produced by the operation of other equipment) that enters equipment by direct coupling.
Radiated interference	Interference resulting from radiated electromagnetic energy that enters equipment.
Impedance	Symbol, Z. Unit, ohm (Ω). The total opposition offered by a circuit to the flow of ac current. It is the vector sum of resistance and reactance; $Z = R + K\frac{(2\pi fL - 1)}{2\pi fC}$ where: Z = ac impedance in ohms R = simple opposition to current flow, i.e., dc resistance, in ohms j = the square root of -1, an imaginary number f = frequency, in Hertz π = pi, 3.1416, the ratio of the circumference of a circle to its diameter L = value of circuit inductance, in Henrys C = value of circuit capacitance, in farads
Resistance	Symbol, R. Unit, ohm (Ω). The simple opposition to current flow. The "real" part of impedance. Defined as that factor by which the mean-square conduction current must be multiplied to determine the corresponding power lost by dissipation as heat or other permanent radiation loss of electromagnetic energy from the circuit.

Parting Thoughts

The references by Ott and by White were the main sources of information for the original article from which most of the material in this note was taken. According to that article, reference 4 "is probably the finest treatment currently available on the subject."

Courses and seminars on the subject of electromagnetic interference are given regularly throughout the year. Information on these can be obtained from:

IEEE Electromagnetic Compatibility Society

- EMC Education Committee
  345 East 47th Street
  New York, NY 10017
  Phone: (212) 752-6800

- Don White Consultants, Inc.
  International Training Centre
  P. O. Box D
  Gainesville, VA 22065
  Phone: (703) 347-0030

The EMC Education committee has available a videotape: "Introduction to EMC — A Video Training Tape," by Henry Ott. Don White Consultants offers a series of training courses on many different aspects of electromagnetic compatibility. Most organizations that sponsor EMC courses also offer in-plant presentations.

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References

1. Clark, O.M. 1979. Electrostatic Discharge Protection Using Silicon Transient Suppressors. Proceedings of the Electrical Overstress/Electrostatic Discharge Symposium. Reliability Analysis Center, Rome Air Development Center.

2. King, W. M. and D. Reynolds. 1981. Personnel Electrostatic Discharge: Impulse Waveforms Resulting From ESD of Humans Directly and Through Small Hand-held Metallic Objects Intervening in the Discharge Path. In: Proceedings of the IEEE Symposium on Electromagnetic Compatibility, pp. 577-590.

3. Ott, H. 1981. Digital Circuit Grounding and Interconnection. In: Proceedings of the IEEE Symposium on Electromagnetic Compatibility, pp. 292-297.

4. Ott, H. 1976. Noise Reduction Techniques in Electronic Systems. New York: Wiley.

5. 1981 Interference Technology Engineers' Master (ITEM) Directory and Design Guide. R. and B. Enterprises, P. O. Box 328, Plymouth Meeting, PA 19426.

6. Smith, L. Nov. 1979. A Watchdog Circuit for Microcomputer Based Systems. Digital Design, pp. 78-79.

7. TranZorb Quick Reference Guide. General Semi-conductor Industries, P.O. Box 3078, Tempe, AZ 85281.

8. Tucker, T.J. 1968. Spark Initiation Requirements of a Secondary Explosive. Annals of the New York Academy of Sciences, Vol. 152, Article I, pp. 643-653.

9. White, D. 1973. Electromagnetic Interference and Compatibility, Vol. 3: EMI Control Methods and Techniques. Don White Consultants.

10. White, D. 1981. EMI Control in the Design of Printed Circuit Boards and Backplanes. Don White Consultants.

Warranty Claims

Advanced Energy® products are warranted to be free from failures due to defects in material and workmanship for 12 months after they are shipped from the factory (please see warranty statement, below, for details).

In order to claim shipping or handling damage, you must inspect the delivered goods and report such damage to AE within 30 days of your receipt of the goods. Please note that failing to report any damage within this period is the same as acknowledging that the goods were received undamaged.

For a warranty claim to be valid, it must:
- be made within the applicable warranty period
- include the product serial number and a full description of the circumstances giving rise to the claim
- have been assigned a return authorization number (see below) by AE Customer Service

All warranty work will be performed at an authorized AE service center (see list of contacts at the front of the manual). You are responsible for obtaining authorization (see details below) to return any defective units, prepaying the freight costs, and ensuring that the units are returned to an authorized AE service center. AE will return the repaired unit (freight prepaid) to you by second-day air shipment (or ground carrier for local returns); repair parts and labor will be provided free of charge. Whoever ships the unit (either you or AE) is responsible for properly packaging and adequately insuring the unit.

Authorized Returns

Before returning any product for repair and/or adjustment, call AE Customer Service and discuss the problem with them. Be prepared to give them the serial number of the unit and the reason for the proposed return. This consultation call will allow Customer Service to determine if the unit must actually be returned for the problem to be corrected. Such technical consultation is always available at no charge.

Units that are returned without authorization from AE Customer Service and that are found to be functional will not be covered under the warranty (see warranty statement, below). That is, you will have to pay a retest and calibration fee, and all shipping charges.

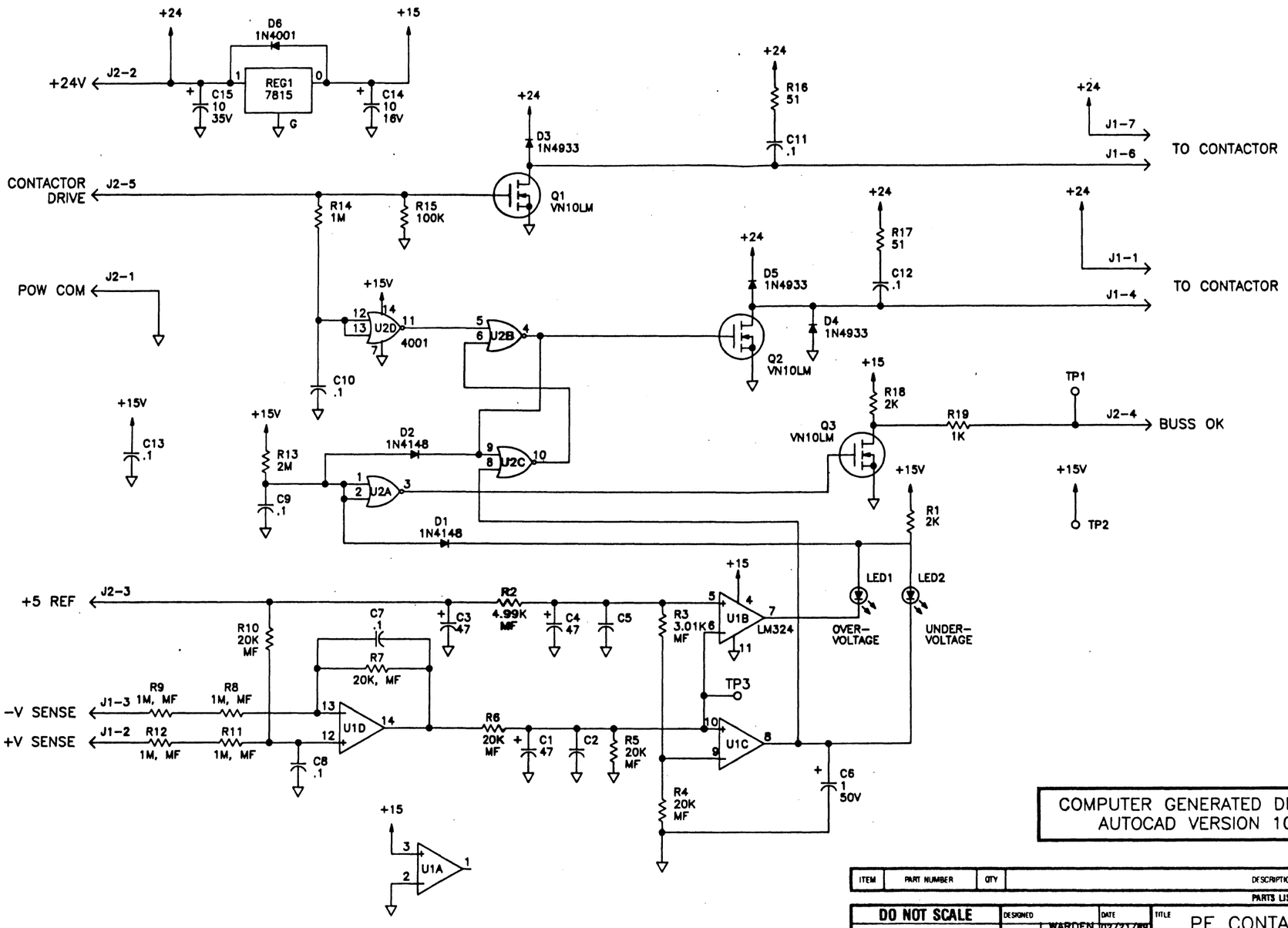
Upgrading Units

AE's products are continually changing as ways to improve them are discovered. AE is happy to upgrade older units so that they reflect recent improvements. The fee for upgrading a unit will be a percentage of the current list price, based on the age of the unit. Such an upgraded unit will carry a 6-month warranty (which will be added to any time remaining on the original warranty). Contact Customer Service for specifics on getting an older unit upgraded to the current revision level.

Warranty

The seller makes no express or implied warranty that the goods are merchantable or fit for any particular purpose except as specifically stated in printed AE specifications. The sole responsibility of the Seller shall be that it will manufacture the goods in accordance with its published specifications and that the goods will be free from defects in material and workmanship. The seller's liability for breach of an expressed warranty shall exist only if the goods are installed, started in operation, and tested in conformity with the seller's published instructions. The seller expressly excludes any warranty whatsoever concerning goods that have been subject to misuse, negligence, or accident, or that have been altered or repaired by anyone other than the seller or the seller's duly authorized agent. This warranty is expressly made in lieu of any and all other warranties, express or implied, unless otherwise agreed to in writing. The warranty period is 12 months after the date the goods are shipped from AE. In all cases, the seller has sole responsibility for determining the cause and nature of the failure, and the seller's determination with regard thereto shall be final.

REV	ECO	DESCRIPTION OF CHANGE		DRAWN	CHECKED	APPROVED
A	–	ORIGINAL ISSUE				
B	PE116	INDICATED PINS THAT GO TO CONTACTOR	2/17/87	BDS	LW	RDP
C	ID108	C1,3,4 WERE 10V	12/26/88	JN		SA
D	PE223	REDRAWN ON CAD WITH NO CHANGE		LW 3/1/89	SR 3/1/89	



NOTES (UNLESS OTHERWISE SPECIFIED):

1. ALL RESISTORS ARE 1/4W CF, 5%; RESISTANCE VALUES ARE IN OHMS.
2. ALL CAPACITANCE VALUES ARE IN MICROFARADS.

COMPUTER GENERATED DRAWING
AUTOCAD VERSION 10.0

ITEM	PART NUMBER	QTY	DESCRIPTION

PARTS LIST

DO NOT SCALE	DESIGNED	L.WARDEN	DATE 02/21/89
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES	DRAWN	SR	3/1/89
TOLERANCES XX = ±.020 .XXX = ±.010 ∅ = ±.002 X/X = ±1/32 ∠ = ±0°30	CHK'D		
	PROJ ENG		3/1/89
PARTS TO BE FREE OF BURRS BREAK ALL EDGES	PROD ENG		
	MATERIAL	N/A	
	FINISH	N/A	
	TITLE BLOCK REV D		

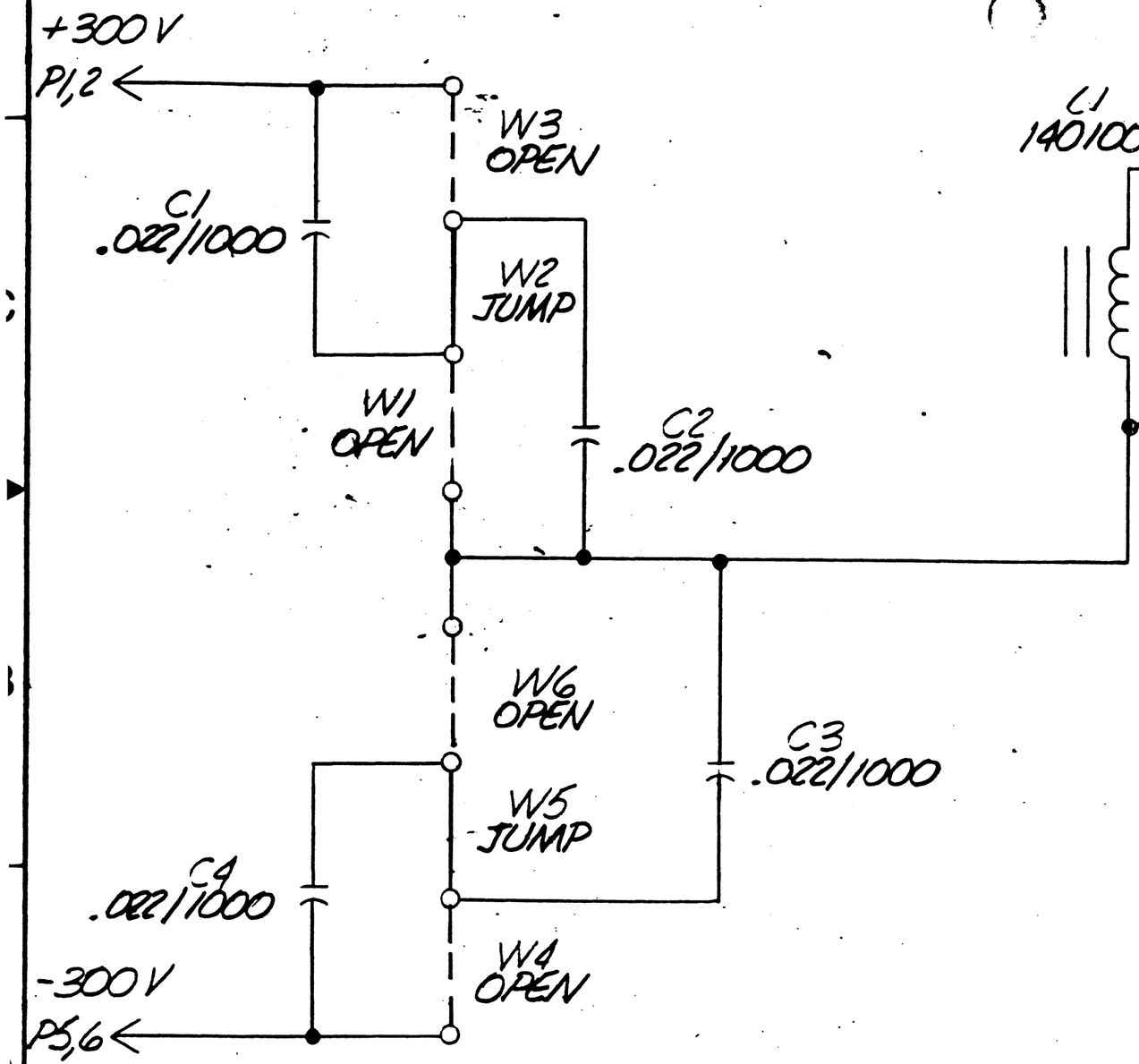
TITLE: PE CONTACTOR SUPPORT SCHEM

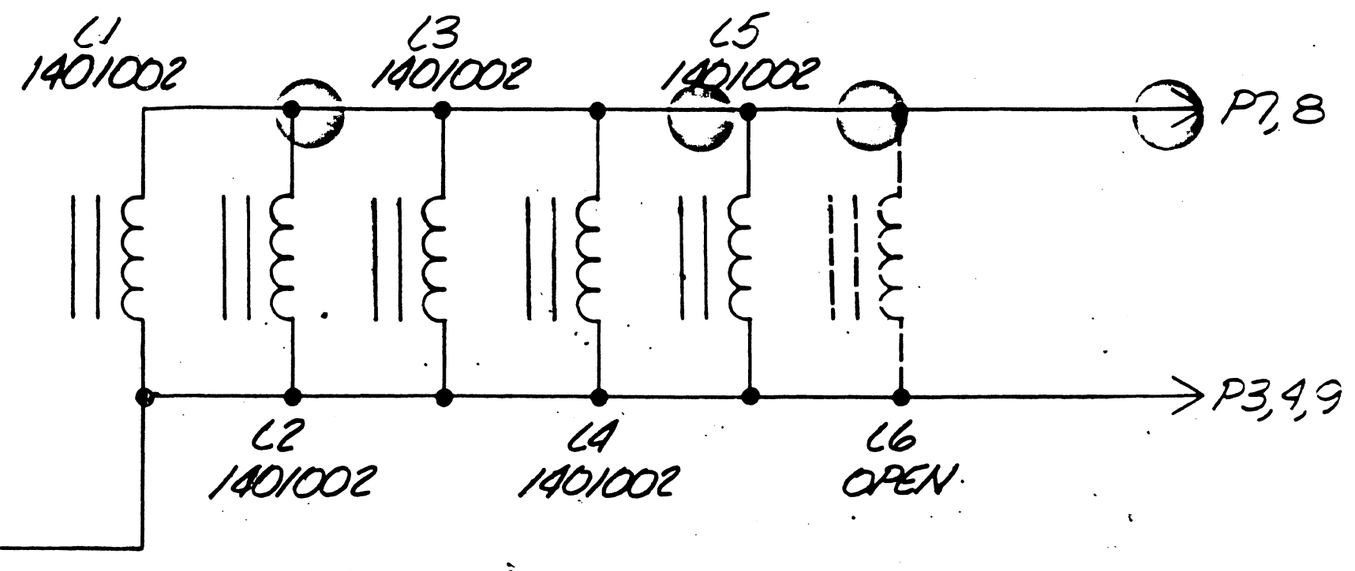
C | DRAWING NUMBER 5032138 | REV D

SCALE NTS | SHEET 1 OF 1

ADVANCED ENERGY®

REV.	E.C.O.	DESCRIPTION OF CHANGE	DATE	APP.
A	–	ORIGINAL ISSUE LPK	9-13-4	





DO NOT SCALE

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ITEM NO	PART NO	QTY.	DESCRIPTION

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
± 1/32"	2 PLACES ± .015 3 PLACES ± .005	± 0° 30'

PARTS TO BE FREE OF BURRS
BREAK ALL EDGES
UNLESS OTHERWISE SPECIFIED ALL SURFACES

DRAWN GK 8-13-4
CHK'D
PROJ ENG
MFG ENG
MATERIAL —
FINISH —

Advanced Energy
Power Sources for Industry
Fort Collins, CO 80525, USA

TITLE: PE 100 KHz FREQ. MOD.

SIZE B | DRAWING NO 3032156 | REV A

SCALE | WT | SHEET 1 OF 1

REV	E.C.O.	DESCRIPTION OF CHANGE	DATE	APP.
C	PEP-62	R3 1.3K TO 1.00K; R4 120Ω TO 113Ω MF	2-25-8	L.H.

REV.	E.C.O.	DESCRIPTION OF CHANGE	DATE	APP.
01		ORIGINAL ISSUE	9-5-5	
A	-	RELEASE	8-11-86	
B	PE 127	P1 WAS J1, P2 WAS J2, D4 WAS D2, D2 WAS D4 D6 WAS D8, D8 WAS D6, F3 WAS R5 ; ADDED R8, ADDED W1-4, W8, W11, W12, W15 & W17-24 ADDED J6 & J7 ; REMOVED PARALLEL DIO AT D2 & D4 ; REMOVED P9 FROM FREQ. MODULE BAH	4/8/87	

P1
1 A-DRIVE
3 B-DRIVE
4 O.C.
5 B-CON
6 A-CON
2 POWCOM
7 +24VDC F3 250V 2A
10 HEATSINK GROUND FOR 2N6678, MJE 13007, LM350
C4 470 35V +
R3 100K MF
C5 47 16V +
R4 113Ω MF
REG1 LM350
D5 IN4001
P4 2 6 5 4 3 7 1
DUAL ISO-DRIVE 1302016
P2 3 4 5 6
-300V RETURN
+300V
P1 4 3 1 2
P2 1 2
W13 W14
P3 1 2 3 4
Q1 MJE 13007
Q2 GSRU 15040
Q3 MJE 13007
Q4 GSRU 15040
C2 .0033 400V
C3 .0033 400V
J2
J1 W18
R6 150Ω 25W
W17
D1 MR856
L1 1402008
W11 D6 UES706 W1
J6
W2 W3 W4
L2 1402008
W15 D8 UES706 J7
W19
R7 150Ω 25W
W20
J3
D7 UES706
W12
W8
W21 W5
W22
W6
W16
D2 SEE D9 600K
D9 UES706
D3 MR856
R2 1/10W
J4
D4 SEPCOOK
R1 1/10W
T1 100 TURNS 1411002
P1,2 P3,4
W7
100KHZ FREQUENCY MODULE P5,6
C1 1.0 400V
R8 620K
NE2
F2 8 ABC
F1 8 ABC
W10
W9
L3 1411005
P2 11 12 8 9 1
W24 W23
T2 1461005
AC OUTPUT

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ITEM NO.	PART NO.	QTY.	DESCRIPTION

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
± 1/32"	2 PLACES ± .015 3 PLACES ± .005	± 0° 30'

PARTS TO BE FREE OF BURRS
BREAK ALL EDGES
UNLESS OTHERWISE SPECIFIED ALL SURFACES

		DATE
DRAWN	ER	9/5/5
CHK'D	AW	9/6/85
PROJ. ENG.	ADE	9/10/85
MFG. ENG.		8-11-86
MATERIAL		
FINISH		

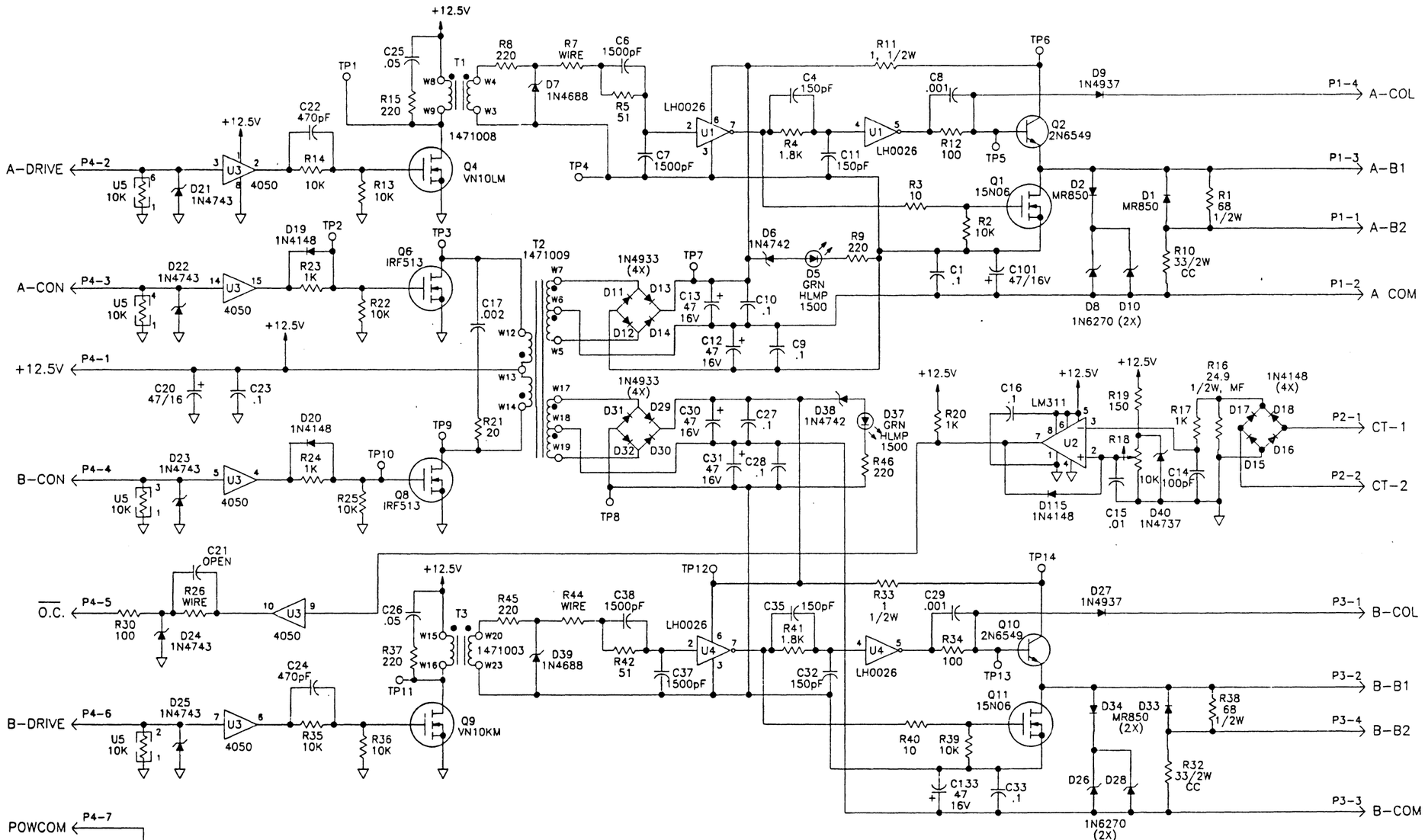
Advanced Energy
Power Sources for Industry
Fort Collins, CO 80524 USA

TITLE: 1.25 KW (HIGH FREQ) INVERTER SCH

C | DRAWING NO. 5032225 | REV. C

SCALE | REF | SHEET 1 OF 1

REV	ECO	DESCRIPTION OF CHANGE	DRAWN	CHECKED	APPROVED
A	–	ORIGINAL ISSUE			
B	–	MISC. CORRECTIONS. 10-13-88	GKC	RDP	RDP
C	MDX 1110	+12.5V WAS +15V			



NOTES (UNLESS OTHERWISE SPECIFIED):

1. RESISTANCE VALUES ARE IN OHMS, 1/4W, ±5%, CF.
   CAPACITANCE VALUES ARE IN MICROFARADS.

DO NOT SCALE	SIGNATURE	DATE
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES INTERPRET PER ANSI Y14.5M — 1982	DESIGNED	
TOLERANCES .XX = ±.020 .XXX = ±.010 Ø = ±.005 X/X = ±1/32 ∠ = ±2°	DRAWN PRAY	09-23-88
PARTS TO BE FREE OF BURRS BREAK ALL EDGES	CHECKED CHOCK	09-23-88
	PROJ ENG PRAY	09-23-88
	PROD ENG	
	THIRD ANGLE PROJECTION	
	TITLE BLOCK REVISION E.	

TITLE: DUAL ISO DRIVE 88 SCHEMATIC

C | DRAWING NUMBER 5032516 | REV C

SCALE NTS | SHEET 1 OF 1

ADVANCED ENERGY®

				LAWLESS	ANDERS	GJ
A	–	ORIGINAL ISSUE, SIMILAR TO 5032624-A				
B	UNI 191	ISO-RELAY ASSY WAS FR105	5/22/92	EM	SS	MT
C	PE 426	ADDED; 100uH INDUCTOR BETWEEN W2 & P14				

220 VAC
25A CIRCUIT BREAKER
LINE FILTER
K1
F1 AGC2 50 70W
MDA3506 BR1
V250LA40A
51K 2W
C1 2100 350V
+300
-300
W4
W3
F2 AGC2
V250LA40A (3X)
FRONT PANEL POWER SWITCH
ISO-RELAY ASSY
FAN 148VKZ81
BRN
BLU
P2-1
P2-2
T1 DL80
D3
D4
D1
D2
MR501 (4X)
C2 4700/35
C3 470/35
+24V
-24V
SUPPORT
J3-6
J3-7
J1-1
J1-2
J1-7
J1-4
J1-6
J1-5
J2-6
J2-5
J2-3
J2-4
J2-5
J2-2
P4
INVERTER
P10
P2-6
P2-5
P1-7
P1-6
P1-5
P1-3
P1-1
P2-4
P2-3
P1-4
P1-2
P1-10
P11
D6 1N4148
F3 AGC8
P2-11
P2-12
P2-8
P2-9
P2-1
M4 ZNR14K102
M5 ZNR14K102
M6 ZNR14K102
W24
W25
C4 1.0/400V
INVERTER
LP8
P9
D5 1N4148
F1 AGC8
M1 ZNR14K102
M2 ZNR14K102
M3 ZNR14K102
F2 AGC8
P8
XFMR 1462077
T3
W22
W19/T3-T
W18/T3-B
S1
OUTPUT PCB ASSY
W1
C1 1.0/400
C2 1.0/400
100uH
W2
P14
W9
W8
W10
T1 1461045
W11
R1 1.5M 2W
W21
W11
W5
W6
W7
W15
W14
CT2 1411002
CT1 1411002
W13
W28
W29
W26
W27
W16
W17
R2 95.3,MF
D10
D9
1N4148 (4X)
D8
D7
R5 24.9
R4 113 1/2W
VSIG
VSND
ISIG
IGND
+24V
R1 100
P1-2 +24V
P1-9 SIGCOM
P1-1 POWCOM
W2
P6
P2-22
P2-23
P2-17
P2-18
P2-14
P2-15
OC
ADRV
BDRV
BCON
ACON
CNTKR
BOK
LED COM
SURG COM
SIGCOM
POWCOM
LOGIC
P7
P1-16
P2-1
P2-2
P2-3
P2-4
P2-24
P1-23
P1-11
P1-13
P2-5
P1-15
P1-14
P2-25
P1-6
P1-1
P1-3
P2-6
P2-7
P1-12
P2-8
P2-10
P2-9
P2-21
P1-14 XOFF
P1-15 XSON
P1-7 INTLK
P1-13 XSIG+
P1-5 XSIG-
P1-6 XSPT
P1-12 XP
P1-11 XI
P1-4 XV
P1-3 F OUT
FRONT PANEL DISPLAY
P3
J3-5
J3-12
J3-10
J3-8
J3-7
SURGCOM
SIGCOM
POWCOM
J3-3
J3-16
J3-14
J3-18
J3-1
J3-13
J3-11
J3-9
J3-20
J3-22
J3-24
J3-26
J3-19
J3-21
J3-23
J3-25
+5V REF
STPT LED
PLSMA
OUTPUT LED
INTLK LED
ARC LED
OVERTEMP LED
BEM
LCAL LED
POFF
SOFF/RESET
LSON
LSIG+
LP
LV
LI
+5V REF
P1-21
P1-22
P1-19
P1-25
P1-20
P1-24
P1-8
P1-9
P1-7
P1-4
P1-2
P1-10
P2-11
P2-12
P2-13
P2-16
J1-1
J1-2
J1-3
J1-4
J1-5
J1-6
J1-7
J1-8
J1-9
J1-10
J1-11
REMOTE
LOCAL
SOURCE ON
REMOTE
LOCAL
LEVEL
EARTH

NOTES:
1. UNLESS OTHERWISE SPECIFIED:
ALL RESISTANCE VALUES ARE IN OHMS, 1/4W, CF;
ALL CAPACITANCE VALUES ARE IN MICROFARADS.

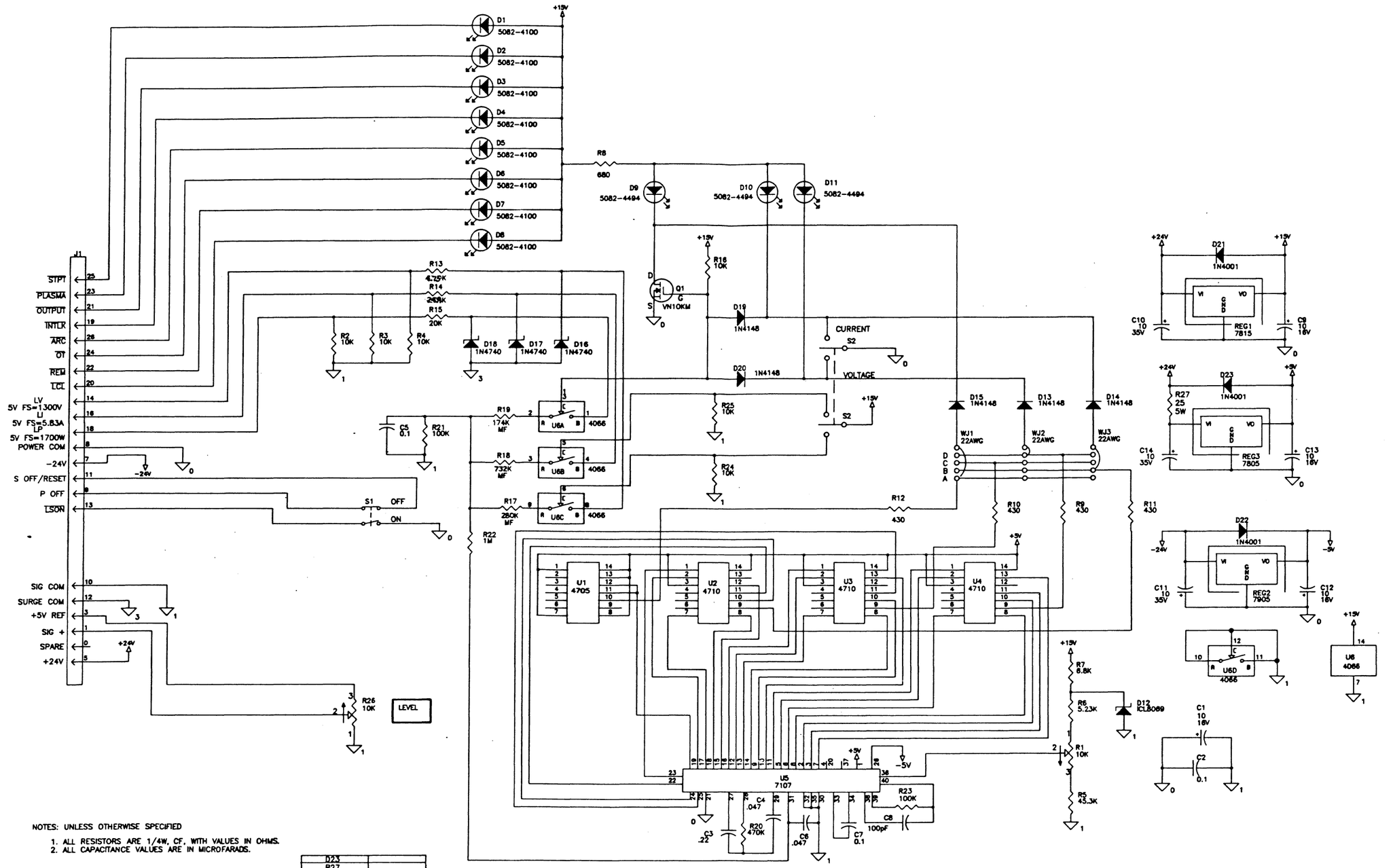
R. PRAY 02/01/90
JOHN D. 2/12/90
GJ 5/15/91

PE2500 100KHZ
50–1000 OHM
SYSTEM SCHEM

5032750 C

NTS 1 1

REV	ECO	DESCRIPTION OF CHANGE	DRAWN	CHECKED	APPROVED
A	–	ORIGINAL ISSUE BASED ON 5032625-A		ANDRES 4-19-91	



NOTES: UNLESS OTHERWISE SPECIFIED

1. ALL RESISTORS ARE 1/4W, CF, WITH VALUES IN OHMS.
2. ALL CAPACITANCE VALUES ARE IN MICROFARADS.

D23	
R27	
Q1	
S2	
C14	
REG3	
U6	
J1	
LAST USED	NOT USED

DO NOT SCALE	SIGNATURE	DATE
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES INTERPRET PER ANSI Y14.5M – 1982	DESIGN: SR	
	DRAWN: SR	2/2/90
TOLERANCES XX ± .020 XXX ± .010 θ ± .005 X/X ± 1/32 ∠ ± 2	ENGR APPR:	5-16-91
PARTS TO BE FREE OF BURRS BREAK ALL EDGES	MFG APPR:	
	TITLE & SIZE APPROVAL	E

PE 2500 100KHZ W/LM 50-1000 OHM DISPLAY SCHEMATIC

D	5032751	A
	NONE	1 1

ADVANCED ENERGY

REV	RFC	DESCRIPTION OF CHANGE	ORIG/DATE	CHK/DATE	APP/DATE
A	-	ORIGINAL ISSUE BASED ON 5032623-A			GJ
B	PE 421	Z2 WAS 50K, R32,33 WERE 63.9K, R28 WAS 2.01M, ADD .1 CAP R34,35 R29, R31 WAS 61.9K	SS 4/28/92	LAWLESS	MT
C	4580	VN10LM WAS = (Q1, 10k WAS = (R20) ADDED U4 GND.	LWS 5/7/92		

U100	311	5,6,7,8	4					
J3					J3,1-7			
U5	4200		3	8				
U7,8,12	4027	16		8				
U10	4025	14		7				
U6	4023	14		7				
U3	4003	14		7				
U1,2,11,16	4001	14		7	U1-C		W4	
U13	3524	15		8			U19	
U15	1412	9			U15-G	8	VR2	
U4,17,18	LM 324	4	11		U4-B		R100	
U9,14,19	TL 084	4	11				Q4	S3
Z2	49.9K RPAK				U14-A,B		P2	Z8 U100,R200,201
Z1,3,4,6	10K RPAK				Z1-E,Z6-C		CR41	J2 R111,131,149
Z5	680 RPAK						C58	WJ10 CR113,115,116
REF DESIG	TYPE	+15V	-15V	GND	SPARE	LED COM	LAST USED	OTHERS USED

NOTES: UNLESS OTHERWISE SPECIFIED
1) RESISTANCE VALUES ARE IN OHMS.
2) CAPACITANCE VALUES ARE IN MICROFARADS.
3) PARTS DESIGNATED WITH '*' ARE NOT PRESENT ON PCB.

DO NOT SCALE

UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES INTERPRET PER ANSI Y14.5M-1982 PERFECT ORIENTATION AT MMC REQUIRED FOR RELATED FEATURES

TOLERANCES: .XX = ±.020 .XXX = ±.010 Ø = ±.005 X/X = ±1/32 ∠ = ±2°

	SIGNATURE	DATE
DRAWN	SR	3/12/90
CHECKED		
APPROVED	GJ	5/15/91

PARTS TO BE FREE OF BURRS AND SHARP EDGES

THIRD ANGLE PROJECTION

TITLE BLOCK REVISION G

TITLE: PE 2500 50-1K OHM LOGIC SCHEMATIC

DRAWING NUMBER 5032752 REV. C

SCALE NONE SHEET 1 OF 1

ADVANCED ENERGY

A	-	ORIGINAL ISSUE	1\15\92	DJZ	JD	BP
B	-	RENUMBERED PINS AT VR1 . ADD R15 R16	3/5/92	DILLON		

I MODE ADJ.

PHASE MODE ADJ.

SPARE

SPARE GATES

NOTES UNLESS OTHERWISE SPECIFIED
1 ALL RESISTANCE VALUES ARE IN OHMS, 1/4W, 5%
2 ALL CAPACITANCE VALUES ARE IN MICROFARADS
3 PER MIL-STD-275 REV

BPRAY	1/15/92
DJZ	1/16/92
JD	1/15/92
BPRAY	1/15/92

PE LOGIC PIGGY
PHASE LIMIT
SCHEMATIC

5002799 B

AE, World Headquarters
1625 Sharp Point Drive
Fort Collins, CO 80525 USA
Phone: 970.221.0108 or 970.221.0156
Fax: 970.221.5583
Email: technical.support@aei.com

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